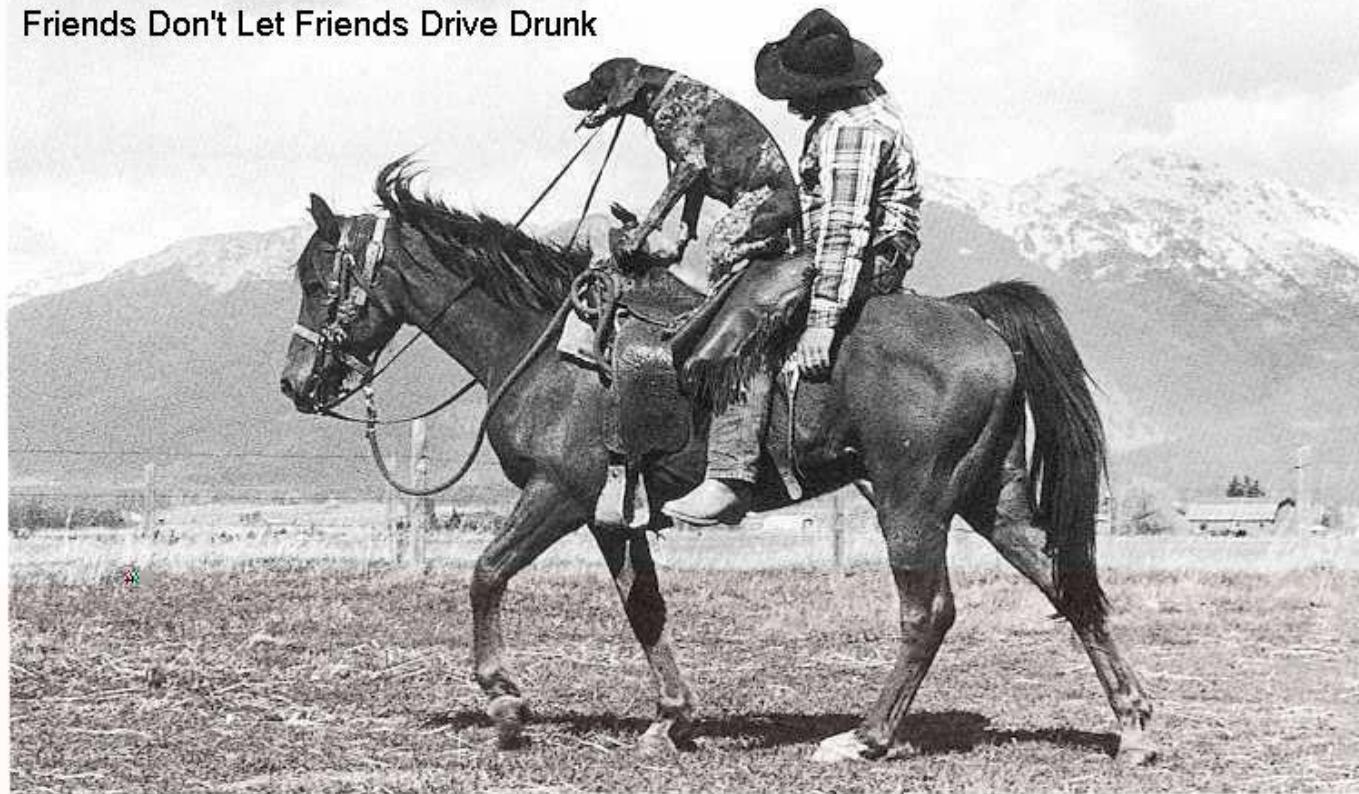


Near the End of the Long Road

Friends Don't Let Friends Drive Drunk



2002
Design Guide

NCHRP 1-37A

Some General Overview Concepts of the 2002 Design Guide For Asphalt Pavements

2002
Design Guide

NCHRP 1-37A

Objective

***Develop and deliver the 2002 guide
for design of new and rehabilitated
pavement structures***

- *Based on mechanistic-empirical principals*
- *Accompanied by the necessary
computational software*
- *For adoption and distribution by AASHTO*

Study Project Statement

- *Development based on (to the greatest possible extent):*
 - *Existing models*
 - *Existing data bases*
 - *No additional laboratory or field testing*

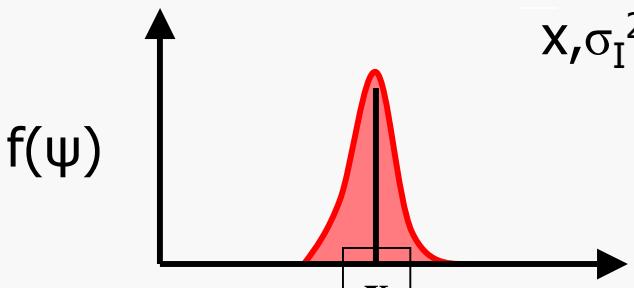
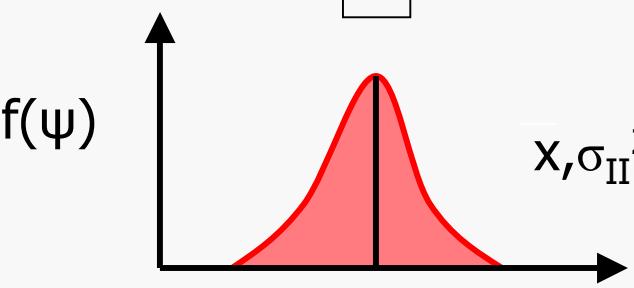
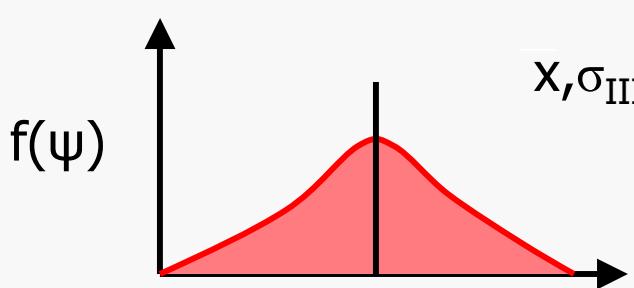
Hierarchical Inputs

- *The 2002 guide will use a hierarchical approach for determining design inputs.*
 - *Level of effort consistent with the importance of the project.*
 - *Allows use of current procedures and provides for inclusion of improved procedures in the future.*

Hierarchical Input (Not Design) Process

- **Level 1 (High Reliability)**
Analysis of special problems
Usually will incorporate Testing
High Visibility/Risk/Cost Projects
- **Level 2 (Medium Reliability)**
Standard Design - Most Cases
(Rigorous but practical)
- **Level 3 (Lower Reliability)**
Lower impact/risk projects

HIERARCHIAL APPROACH (AC MODULUS)

<u>LEVEL</u>	<u>MIX</u>	<u>BINDER</u>	<u>RELIABILITY</u>
1	E* Lab Test	G*, δ Lab Test	
2	E*Predictive equation	G*, δ Lab Test	
3	E*Predictive equation	AC Grade to properties	

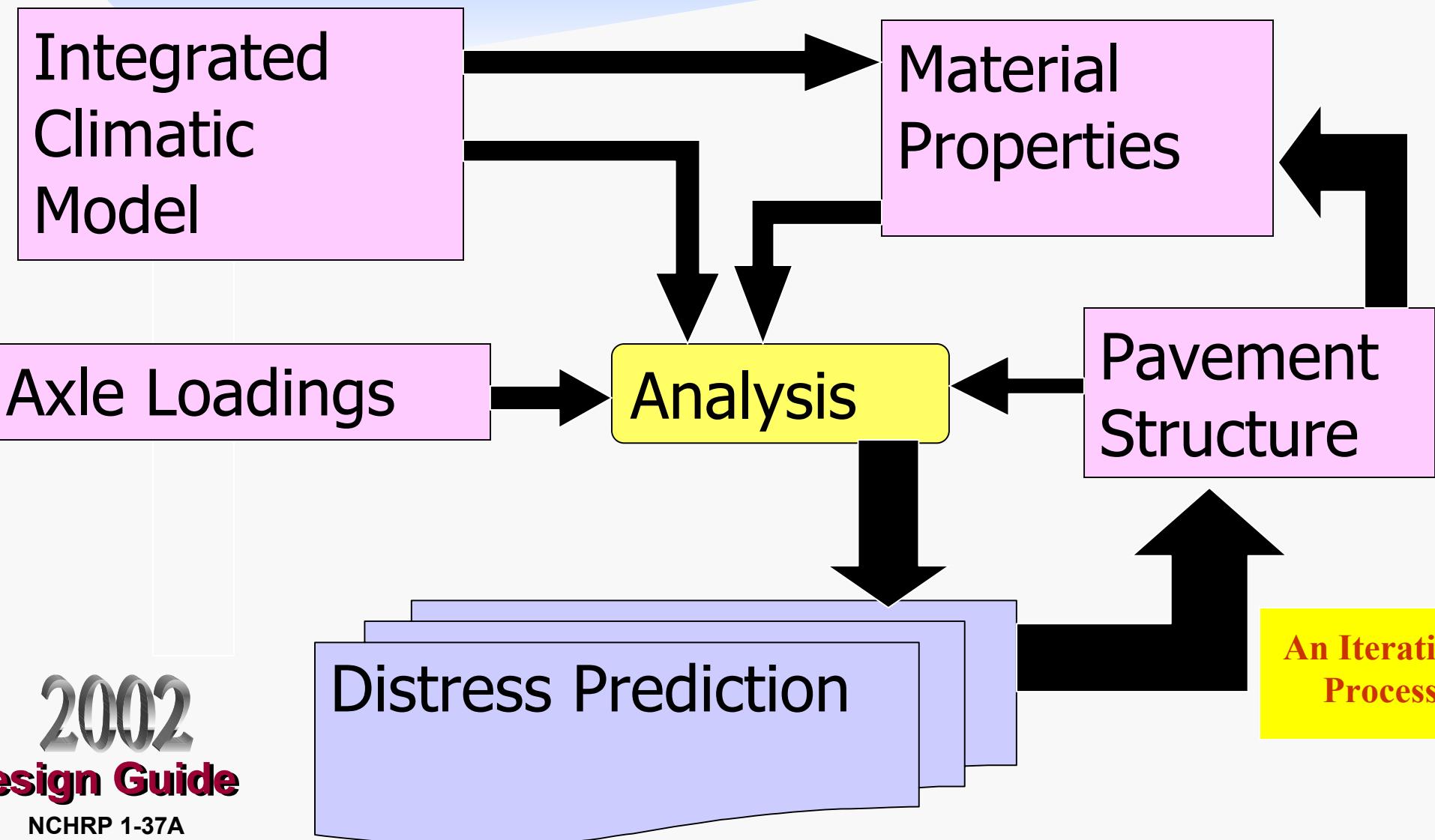
Mechanistic - Empirical Design

- *Calculate stress, strain, or deflection due to traffic or environmental loadings*
- *Relate the number of repetitions to a physical distress such as cracking, rutting, or faulting*
- *Calibrate with observed performance*

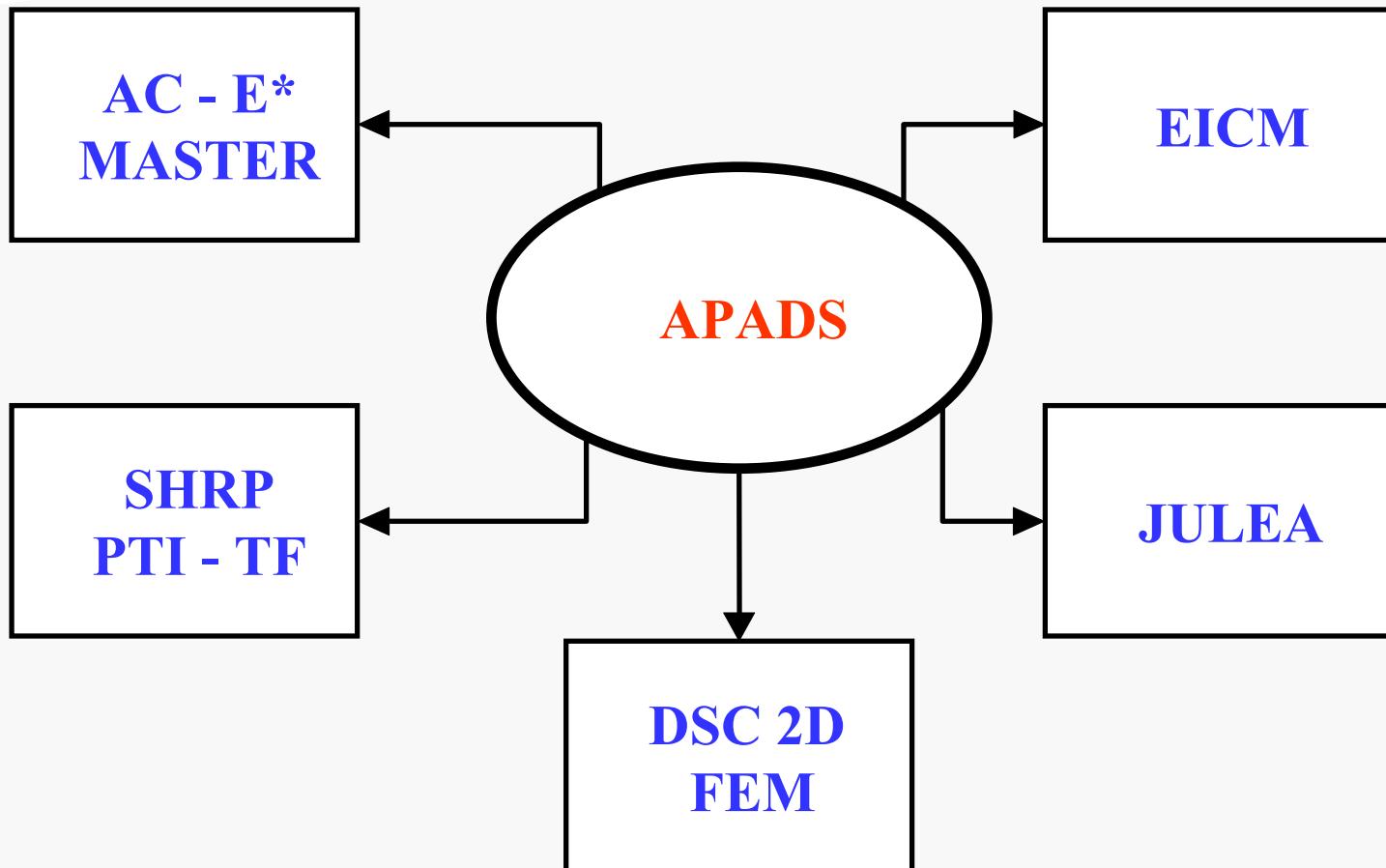
Design Inputs - Common to Flexible and Rigid Teams

- ***1. Subgrade/Foundations***
- ***2. Material Characterization***
- ***3. Environmental Effects***
- ***4. Traffic Loading***
- ***5. Reliability***

2002 Guide Process



Several Major Subroutines



NCHRP 1-37A: 2002 Design Guide

- *Mix Design Properties Integrated into Structural Design*
- *Predicted Individual Distress Types Considered*
 - *Rutting*
 - *Asphalt Layers*
 - *Unbound Layers*
 - *Total Pavement*
 - *Fatigue*
 - *Top Down (Thermal Strain; Aging; Load at 0z < 0.5 inches)*
 - *Bottoms Up (Classic Alligator Cracking)*
 - *Thermal Fracture*
 - *IRI (Replace PSI – PSR Concept of AASHTO Design Guide)*

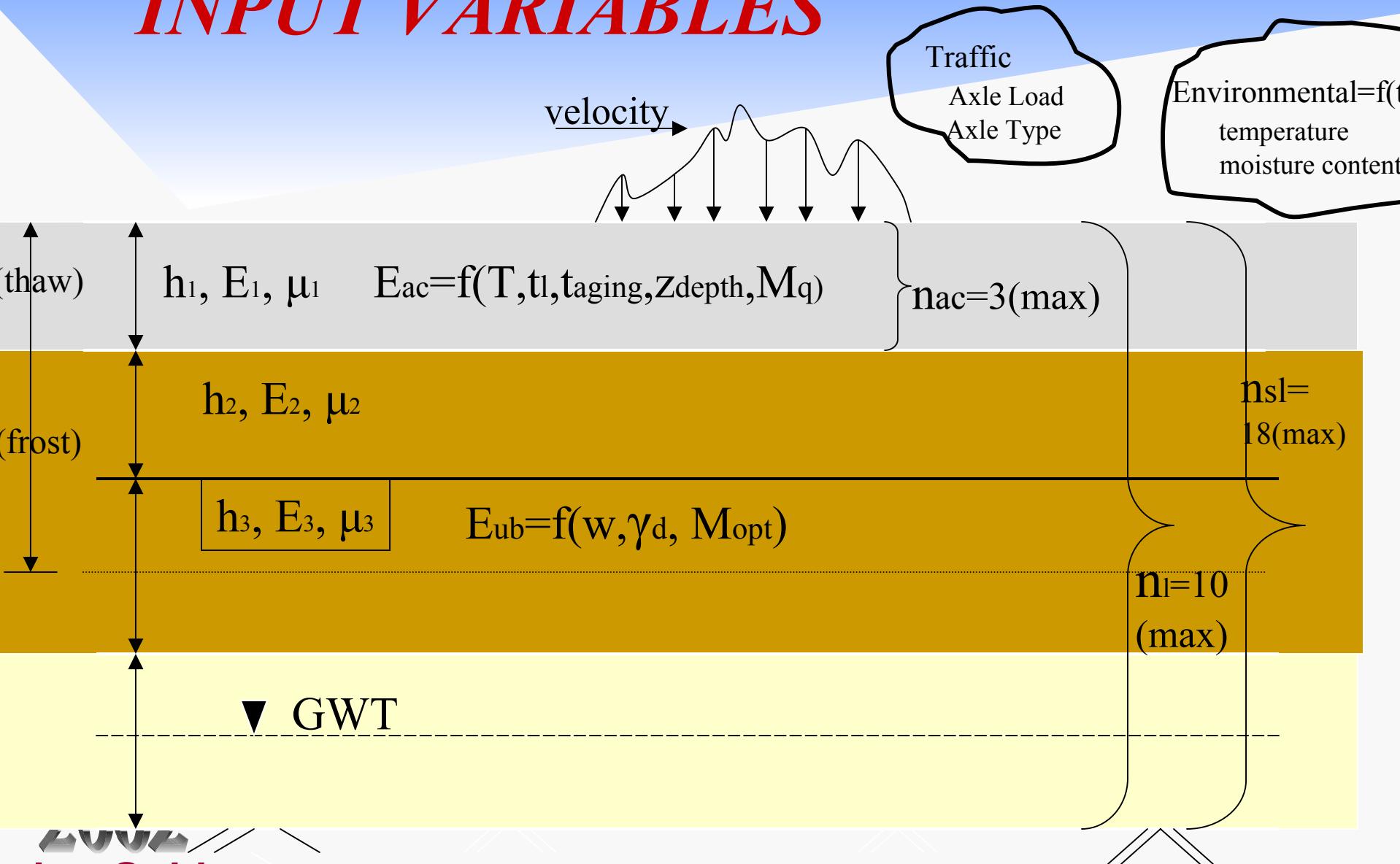
Pavement Response Models/ Analysis Plan

Selected Options

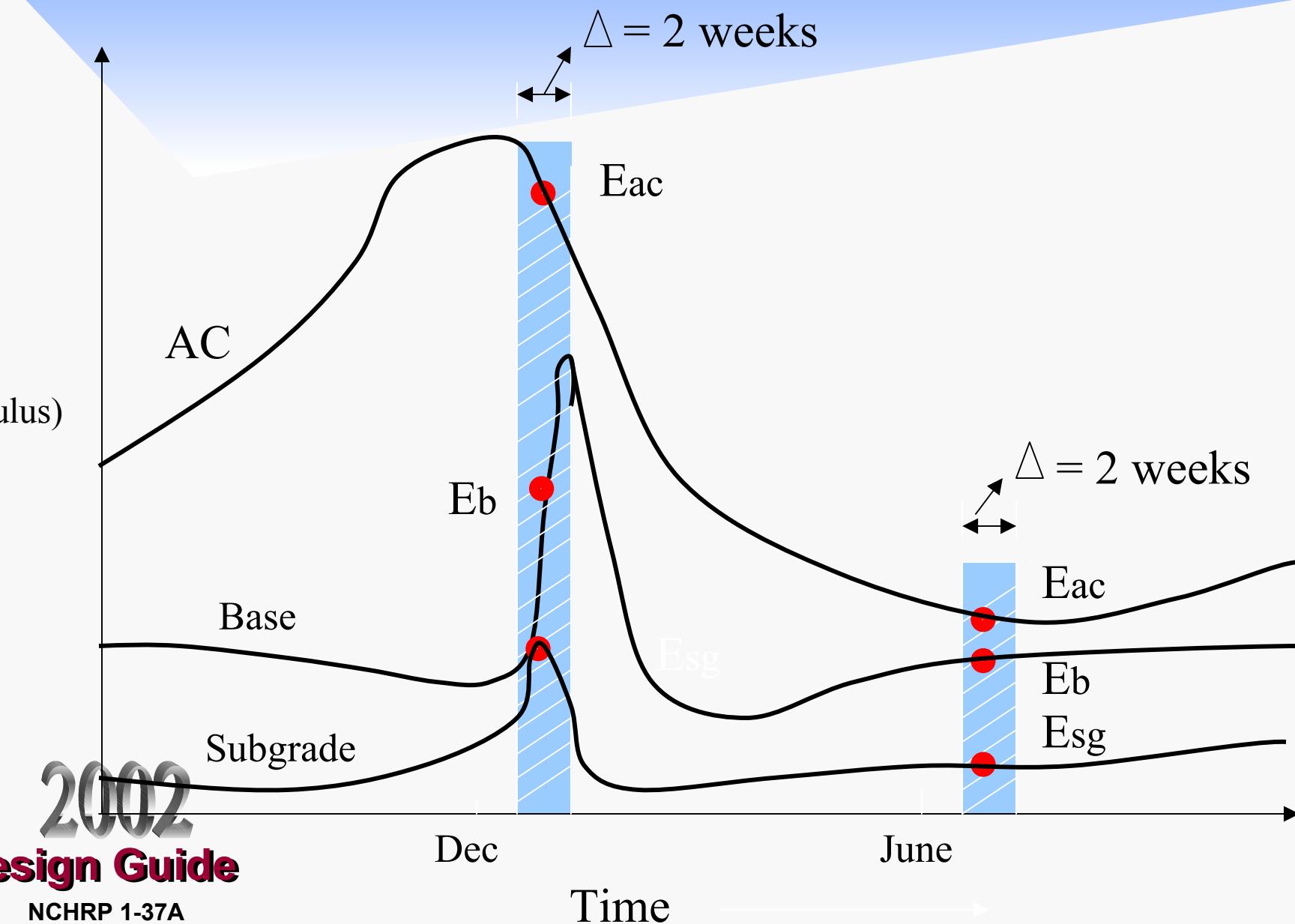
- 1. Multi-Layer Elastic Solution
(Majority of Computations :JULEA)**

- 2. UMd Modified DSC Finite Element Analysis
(For Special Loading Conditions, Non-Linear
Unbound Material Characterization)**

INPUT VARIABLES



ANNUAL MODULUS VARIABILITY



Cumulative Incremental Damage Approach

- *Changes over time (Month) are addressed*
 - *Material strength and stiffness*
 - *seasonal moisture and temperature*
 - *variations in traffic (seasonally and over time)*

Axle Load Spectra

Axe Load (1000 lbs)	Number of Axles			
	Single	Tandem	Tridem	Quad
11-14	5,000	400	100	5
15-18	3000	2000	500	10
19-22	200	5000	800	30
23-26	50	4000	1000	80
27-30	6	2000	1500	100
etc				

Conceptual IRI (Roughness) Model

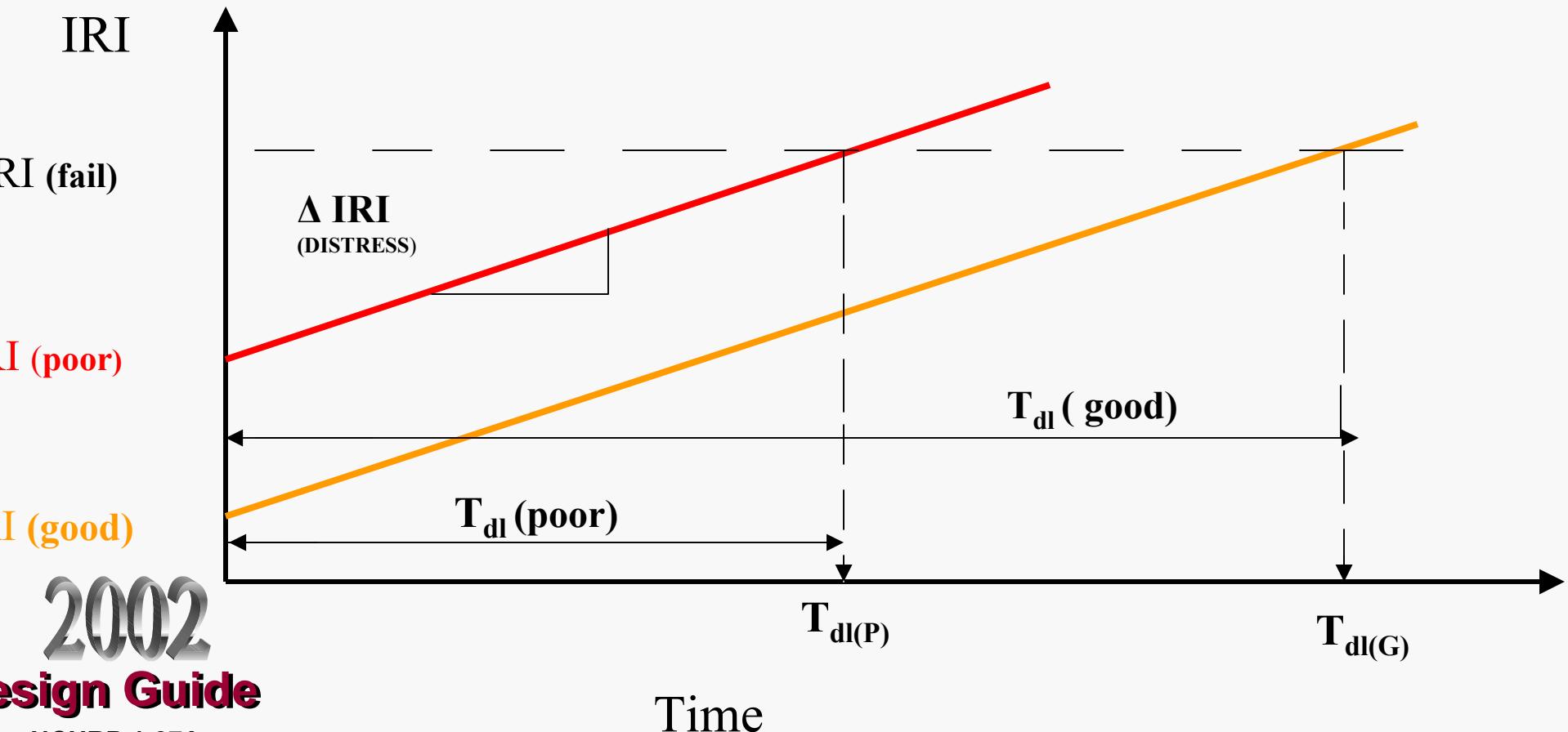
$$\begin{aligned} IRI &= IRI_0 + \Delta IRI \\ \Delta IRI &= f(D_j, S_f) \end{aligned}$$

***IRI₀ = Pavement Smoothness when it
is Newly Constructed***

D_j = Effect of Surface Distresses

***S_f = Effect of Non-Distress Variables
or Site Factor***

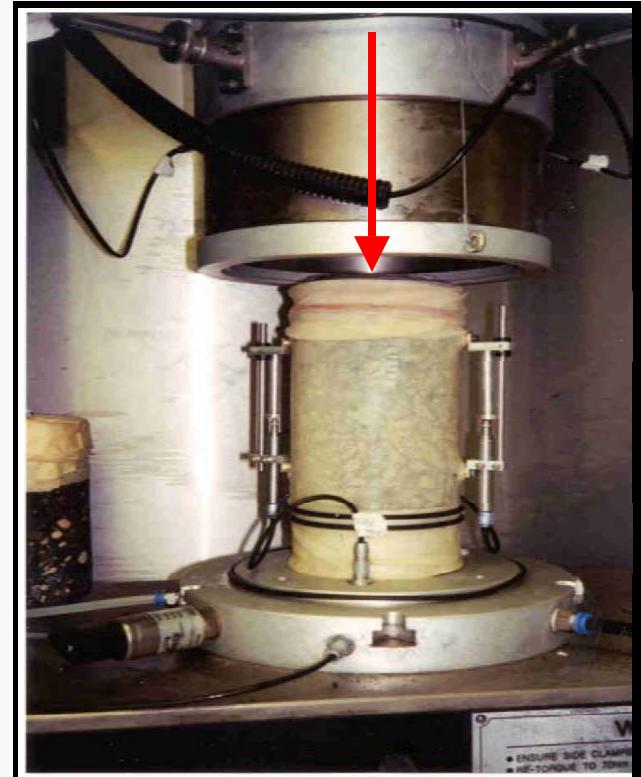
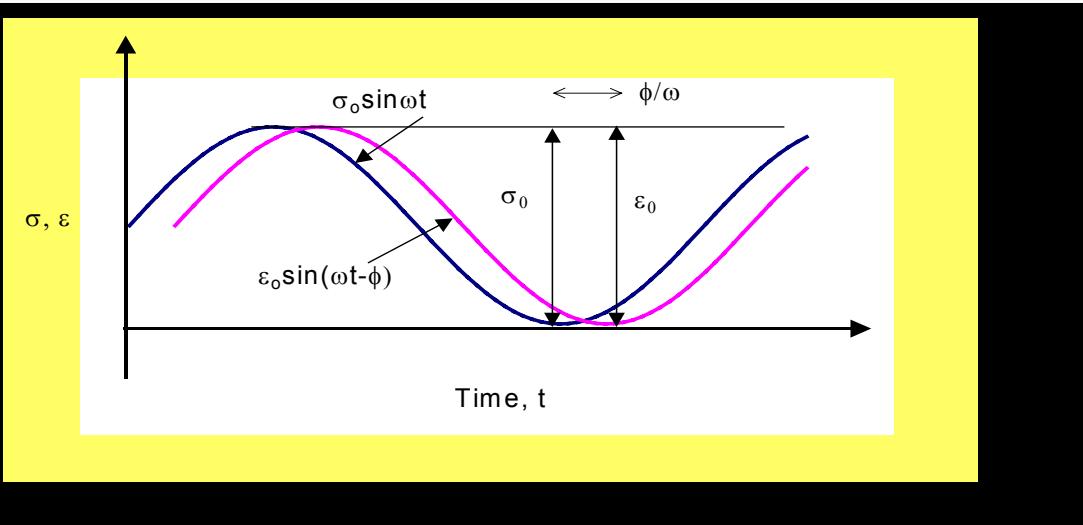
IMPORTANCE OF INITIAL (CONTRACTOR) SMOOTHNESS



Use of Dynamic Complex Modulus (E^*) for Characterizing AC Mixtures in the Design Guide

**2002
Design Guide**

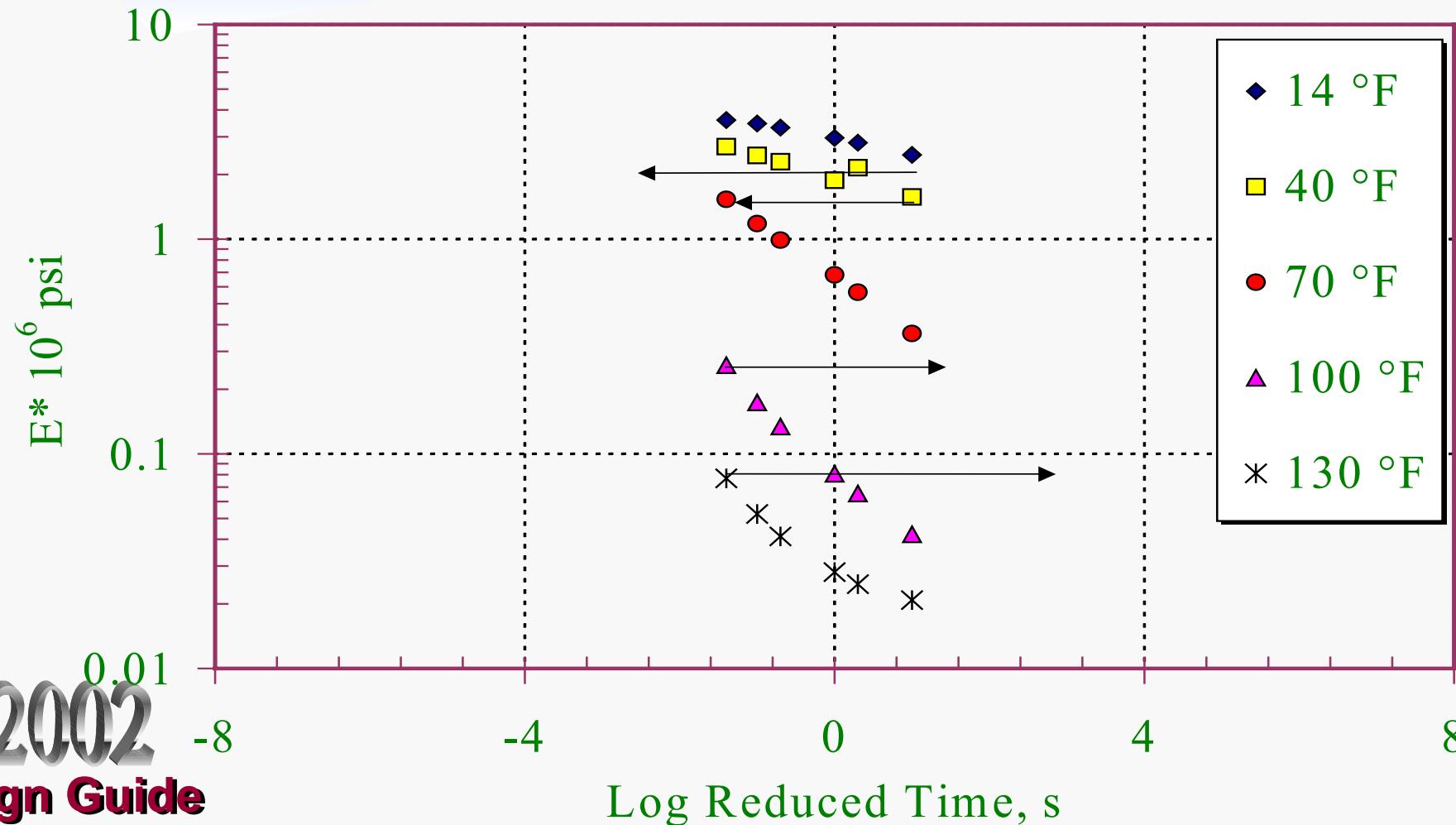
Dynamic Complex Modulus (E^*) and Phase Angle (ϕ) – Viscoelastic Properties



2002
Design Guide

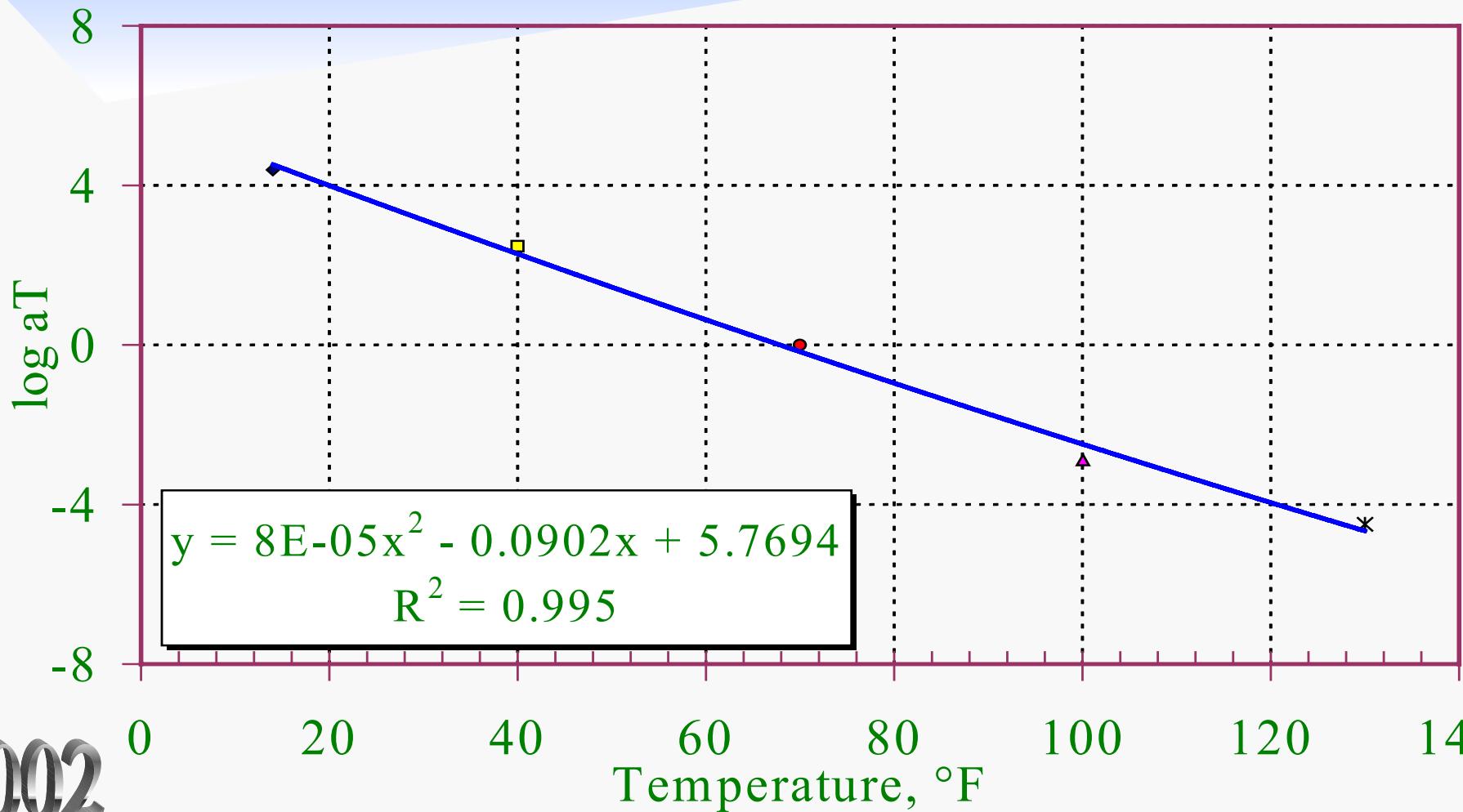
Time-Temperature Superposition Principles-Manual Shifting

SC-64-22



Shift Factor

Shift Factors for SC-64-22

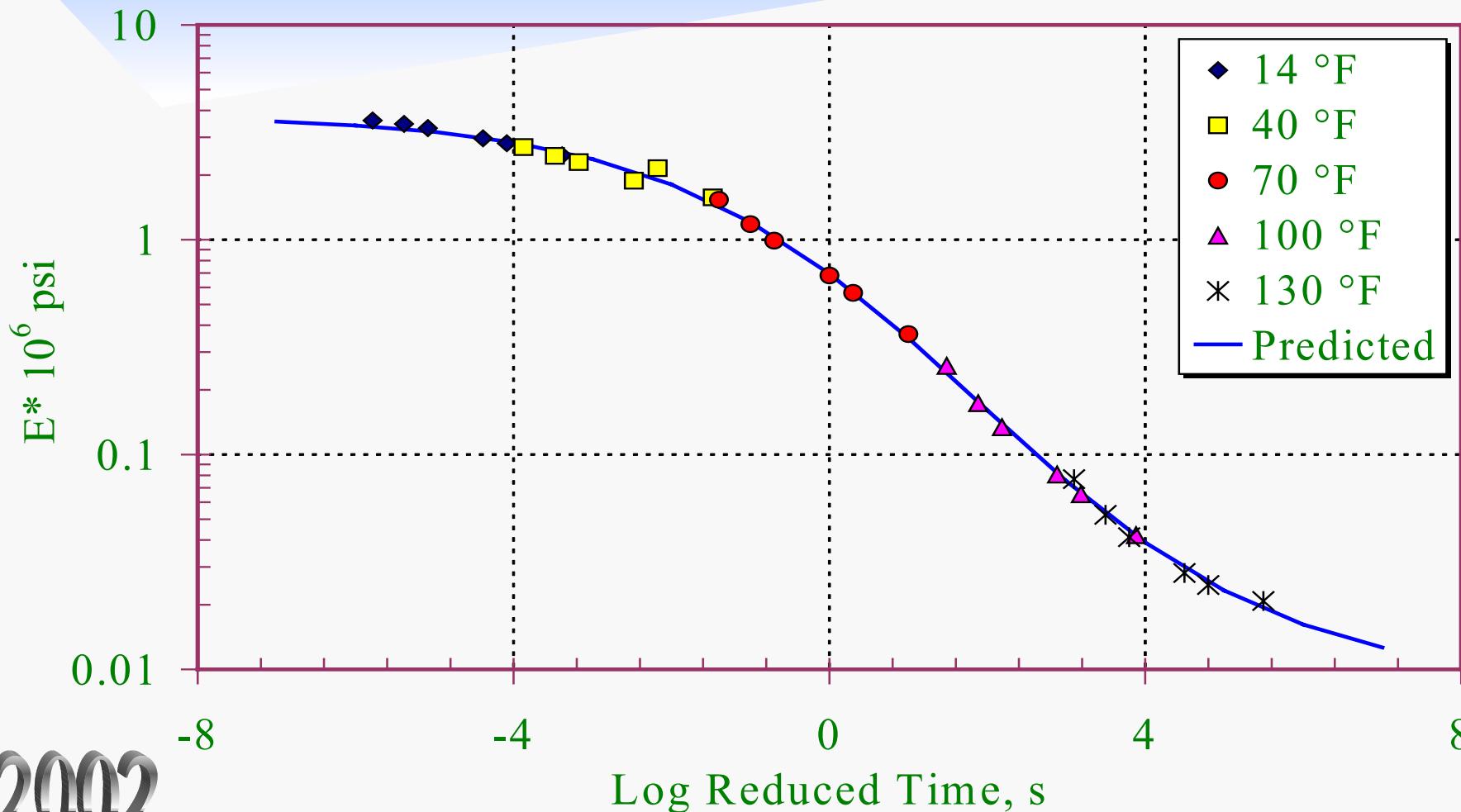


2002

Design Guide

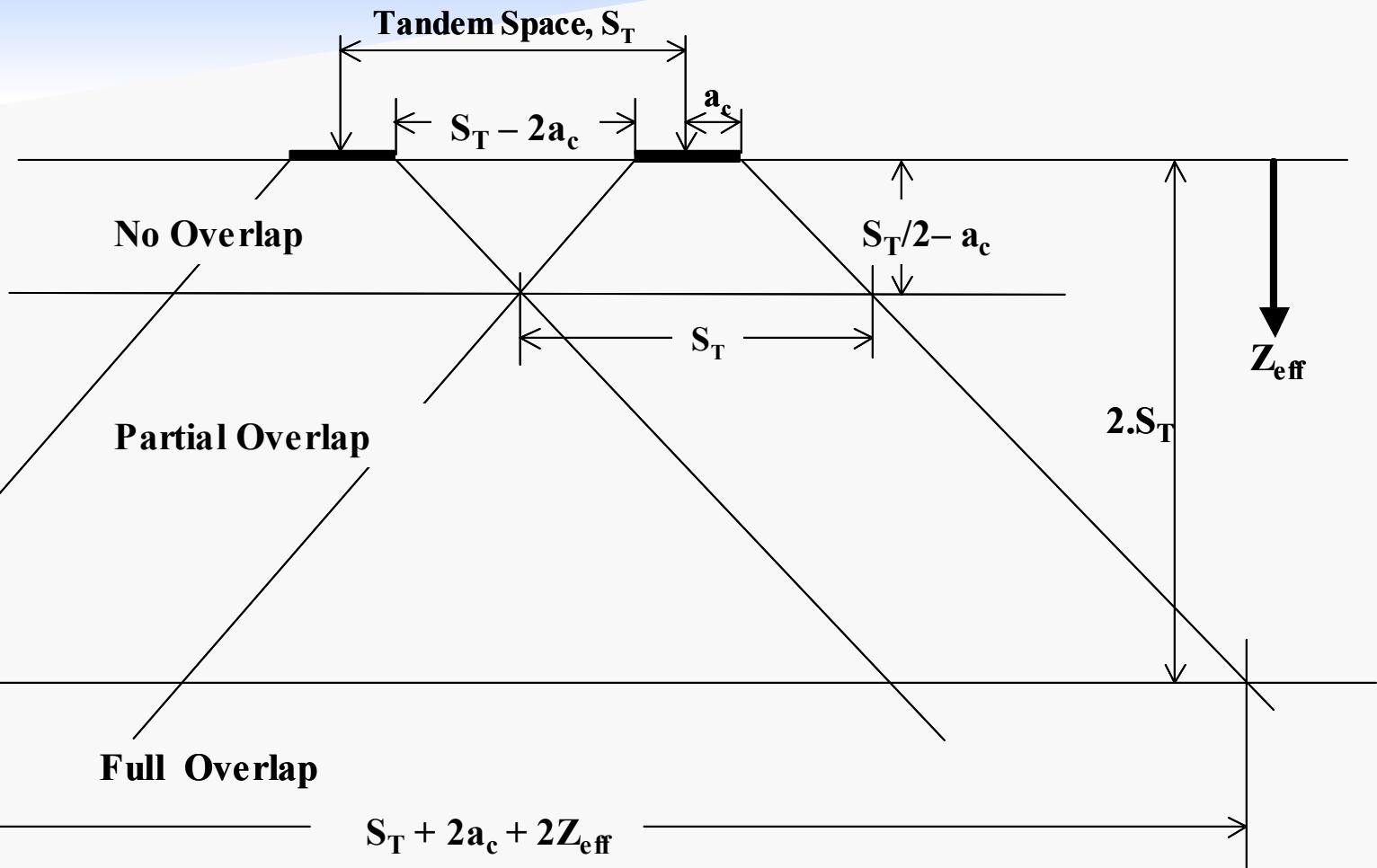
Master Curve – Major 2002 AC Property

SC-64-22



Relationship Between Traffic Velocity and Load Frequency Used in the 2002 Design Guide

Effective Length -Tandem Axle



Typical Calculated Frequency Values as Function of Speed

Type Road Facility	Operating Speed (mph)	Location	Frequency (Hz)		
			Representative AC Layer (4"-12")	Thin AC Layers Wearing Surface (1"-3")	Thick AC Layer Binder/Base (3"-12")
Interstate	60	Mid	15 - 40	45 - 95	10 - 25
		Bottom	5 - 20	30 - 55	5 - 15
State Primary	45	Mid	10 - 30	35 - 70	15 - 20
		Bottom	5 - 15	20 - 40	5 - 10
Urban Street	15	Mid	5 - 10	10 - 25	5 - 10
		Bottom	1 - 5	5 - 15	1.5 - 5
Intersection	0.5	Mid	0.1 - 0.5	0.5 - 1.0	0.1 - 0.25
		Bottom	0.05 - 0.25	0.25 - 0.5	0.05 - 0.15

Unbound Materials (Base-Subbase-Subgrade) Modulus Approach Used in 2002 Design Guide

**2002
Design Guide**

NCHRP 1-37A

Unbound Materials Modulus

New Design – Level 1

<i>Design Type</i>	<i>Input Level</i>	<i>Description</i>	<i>Test/Estimation Method Required</i>
<i>New</i>	1*	Resilient Modulus (M_R)	Use k_1 , $-k_3$ nonlinear coefficients
	1a	Direct lab test	LTPP P-046 and/or NCHRP 1-28A test protocol
	1b	k_i parameter prediction models	Estimate k_i values from standard material properties
	1c	Typical k_i values by material group	Tabular summary of k_i parameters versus soil classification group

* Requires FEM Analysis

Unbound Materials Modulus

New Design – Level 2

<i>Design Type</i>	<i>Input Level</i>	<i>Description</i>	<i>Test/Estimation Method Required</i>
<i>New</i>	2	Correlate M_R from empirical/lab tests	Prediction equations
	2a	Obtain M_R from CBR or R value equations	$M_R = 1155 + 555(R)$ psi or $M_R = 2555(CBR)^{0.64}$
	2b	Obtain M_R from PI/gradation properties	See text for recommended equations
	2c	Convert agency layer coefficient (a_i) experience for base/subbase M_R	$M_R = 30000(a_i/0.14)^3$ psi

Unbound Materials Modulus

New Design – Level 3

<i>Design Type</i>	<i>Input Level</i>	<i>Description</i>	<i>Test/Estimation Method Required</i>
<i>New</i>	3	Soil classification correlations	AASHTO/USCS correlations
	3a	AASHTO classification	Typical M_R range as default for design/optimum conditions
	3b	USCS classification	Typical M_R range as default for design/optimum conditions

Unbound Materials Modulus Rehabilitation – Level 1

<i>Design Type</i>	<i>Input Level</i>	<i>Description</i>	<i>Test/Estimation Method Required</i>
<i>Rehab</i>	1	Backcalculate M_R	FWD tests
		Direct FWD measurement	Use unbound material correction factor: $C_f = E_{\text{Design}} / E_{\text{fwd}}$ ($C_f=0.40$ subgrade; $C_f=0.67$ base/subbase)

Unbound Materials Modulus Rehabilitation – Level 2

<i>Design Type</i>	<i>Input Level</i>	<i>Description</i>	<i>Test/Estimation Method Required</i>
<i>Rehab</i>	2	Correlate M_R from empirical/lab	Predictive equations
	2a	Estimate M_R from DCP and CBR test	Determine penetration resistance (PR) from DCP test then use $CBR = (292/PR^{1.12})$, then $M_R = 2555(CBR)^{0.64}$ psi
	2b	Obtain M_R from CBR or R value equation	$M_R = 1155 + 555(R)$ psi or $M_R = 2555(CBR)^{0.64}$
	2c	Obtain M_R from PI/gradation properties	See text for recommended equations
	2d	Convert agency layer coefficient (a_i) experience for base/subbase M_R	$M_R = 30000(a_i/0.14)^3$ psi

Unbound Materials Modulus Rehabilitation – Level 3

<i>Design Type</i>	<i>Input Level</i>	<i>Description</i>	<i>Test/Estimation Method Required</i>
<i>Rehab</i>	3	Soil classification correlations	AASHTO/USCS correlations
	3a	Typical backcalculated M_R values	Tabular summary of M_R backcalculated values by soil group
	3b	AASHTO classification	Typical M_R range as default for design conditions
	3c	USCS classification	Typical M_R range as default for design conditions

Hierarchical Test Protocols for Assessing Pavement Distress Used in the 2002 Design Guide

2002
Design Guide

NCHRP 1-37A

Methods for Distress Models

	<i>AC Fatigue Cracking</i>	<i>AC Permanent Deformation</i>	<i>AC Thermal Fracture</i>	<i>Unbound Materials Permanent Deformation</i>
<i>Special Analysis</i>	Lab Tests (Flexural Beam) with Shift	Lab Tests (Repeated Load PD) with Shift	SHRP (Mod) Test Protocol L1:T = 0, -10, -20°C Creep Compliance L2:T = -10 °C Creep Compliance	Use Existing Models
<i>National Calibration</i>	1-37A Nationally Calibrated Values	1-37A Nationally Calibrated Values	1-37A Nationally Calibrated Values (Level 3)	1-37A National Calibrated Valu
<i>State/ Regional Calibration</i>	State/Regional Calibrated Values	State/Regional Calibrated Values	State/Regional Calibrated Values	State/Regiona Calibrated Valu
<i>Typical Agency Values</i>	Typical Agency/ Organizational Values	Typical Agency/ Organizational Values	NA	Use Existing Models

AC Fatigue Cracking General Model Form

$$N_f = \beta_{f_1} k_1 \left(\frac{I}{\varepsilon_t} \right)^{k_2 \beta_{f_2}} \left(\frac{I}{E} \right)^{k_3 \beta_{f_3}}$$

$\beta_{f_1}; \beta_{f_2}; \beta_{f_3}$  Adjustment Factors

Level A –Special Analysis

- Fatigue Beam Tests
- Lab Tests with Shift

$$N_f = \beta_{f_1} k_1 \left(\frac{1}{\varepsilon_t} \right)^{k_2 \beta_{f_2}} \left(\frac{1}{E} \right)^{k_3 \beta_{f_3}}$$

k1, k2, k3 from lab fatigue

β_{f_1} selected from user experience; $\beta_{f_2} = \beta_{f_3} = 1$

- i.e., New AC Mixtures; Modified AC
(do not rely on US Calibration Factors)

Level B – National Calibration

- Based upon Results of Research Team 1-37A
- National Calibrated Effort

k_1
 k_2
 k_3 } Initial Shell Oil Values

Initial $\beta_{f_1} = \beta_{f_2} = \beta_{f_3} = 1$

$$N_f = A_f F'' K_{1\sigma} \left(\frac{1}{\varepsilon_t} \right)^{k_2} \left(\frac{1}{E} \right)^{k_3}$$

$$\begin{aligned} k_1 &= A_f F'' K_{1\sigma} \\ k_2 &= 5.0 \\ k_3 &= 1.4 \end{aligned}$$

With

$$A_f = 1.0$$

$$F'' = \left(1 + \frac{13,909 E^{-0.4} - 1}{1 + e^{(1.354 h_{ac} - 5.408)}} \right)$$

$$K_{1\sigma} = (0.0252 PI - 0.00126 PI (V_b) + 0.00673 V_b - 0.0167)$$

Level B – National Calibration

After 1-37A National Calibration

$$k_1' = k_1 \beta_{f_1}$$

$$k_2' = k_2 \beta_{f_2}$$

$$k_3' = k_3 \beta_{f_3}$$

$$\beta_{f_1}; \beta_{f_2}; \beta_{f_3}$$

become National Calibration Factors

Level C – State / Regional Calibration

- From 1-37A National Factors

$$N_f = \beta_{f_1} k_1 \left(\frac{1}{\varepsilon_t} \right)^{k_2 \beta_{f_2}} \left(\frac{1}{E} \right)^{k_3 \beta_{f_3}}$$
$$\left. \begin{matrix} k_1 \\ k_2 \\ k_3 \end{matrix} \right\} 1-37A \text{ National Calibration Factors}$$

- From State/Local Calibration

$$\left. \begin{matrix} \beta'_{f_1} \\ \beta'_{f_2} \\ \beta'_{f_3} \end{matrix} \right\} 1-37A \text{ National Calibration Factors}$$

- Final State Model



$$\begin{aligned} k''_1 &= k'_1 \beta'_{f_1} \\ k''_2 &= k'_2 \beta'_{f_2} \\ k''_3 &= k'_3 \beta'_{f_3} \end{aligned}$$

$$N_f = k''_1 \left(\frac{1}{\varepsilon_t} \right)^{k''_2} \left(\frac{1}{E} \right)^{k''_3}$$

Level D – Typical Agency Values

$$\beta_{f_1} = \beta_{f_2} = \beta_{f_3} = 1$$

$$N_f = k_1 \left(\frac{1}{\varepsilon_t} \right)^{k_2} \left(\frac{1}{E} \right)^{k_3}$$

k_1, k_2, k_3 Prior Agency Experience

i.e., TAI MS-1 (9th Edition)
Witczak Modified Finn (NCHRP 1-10B) Fatigue

$$k_1 = (18.4) (4.32 \times 10^{-3}) C$$

where:

$$C = 10^M$$

$$M = 4.84 \left[\left(\frac{V_b}{V_v + V_b} \right) - 0.69 \right]$$

$$k_2 = 3.29$$

$$k_3 = 0.854$$

Calibration-Validation of 2002 Design Guide

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NCHRP 1-37A

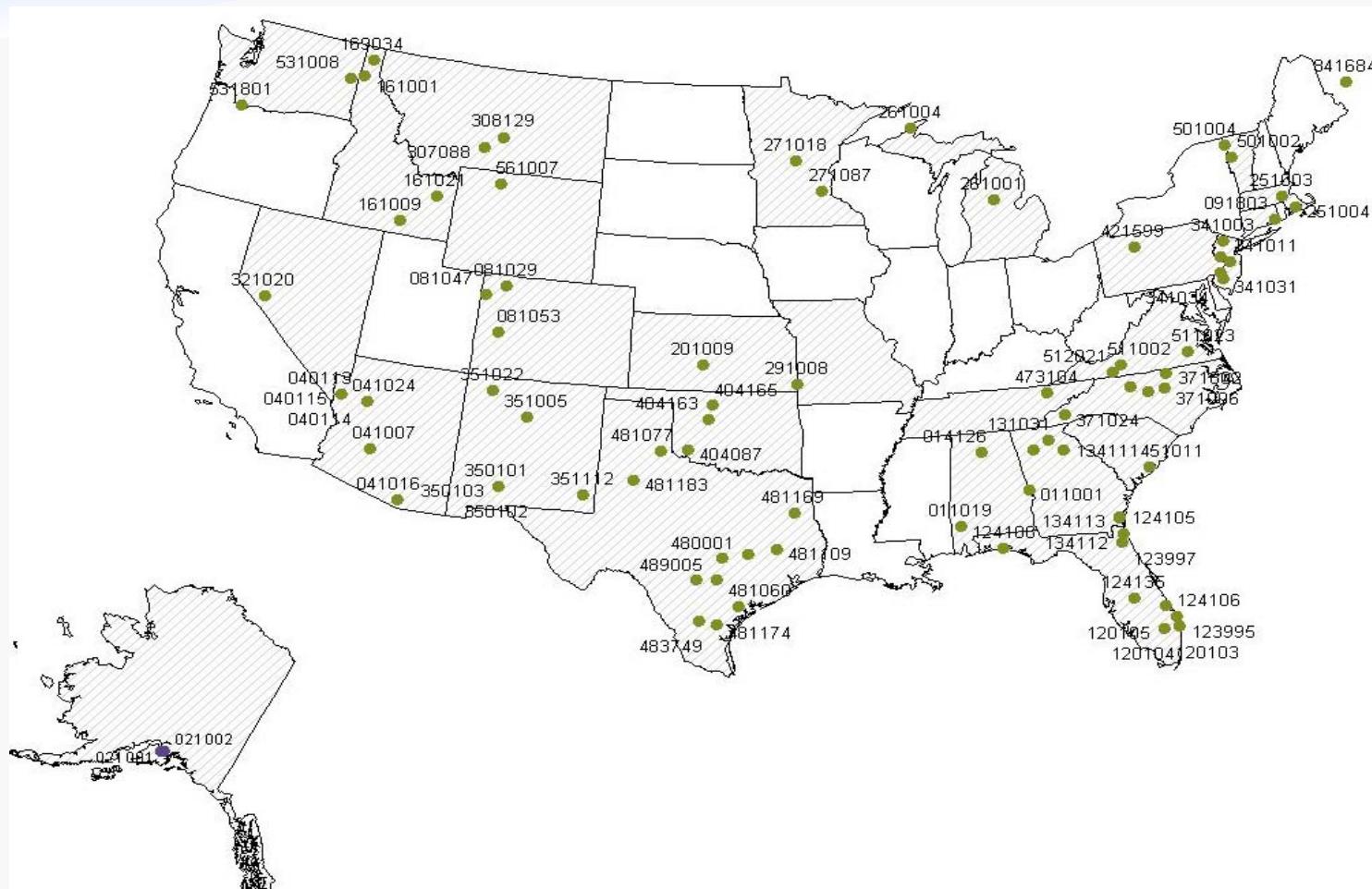
Calibration by Distress Type

- ***THIS IS THE MOST IMPORTANT PART OF THE GUIDE DEVELOPMENT***
- ***M-E models require a process of "calibration" to ensure that they will be reliable models.***
- ***This will require three ongoing steps:***
 - (1) Verification***
 - (2) Calibration***
 - (3) Validation***

Distress Types Calibrated

- ***Rutting***
 - AC Layers
 - Unbound Base/Subbase/Subgrade Layers
 - Total Rut Depth
- ***Fatigue Cracking***
 - Surface Down-Longitudinal Cracking
 - Bottom Up- Alligator Cracking
- ***Transverse Cracking***
 - Possibility for Level 3 Analysis
 - Prior NCHRP 9-19 Model Re-Calibration (39 NA Sections)
- ***IRI***
 - Probably No-IRI Models are Best-Fit from LTPP Section Data
 - IRI Accuracy depends upon predictive accuracy of all other Distress

Distribution of Test Sections Used in Calibration and Validation of New Flexible 2002 Design Guide Model



Field Calibration Factors AC-Rutting

$$\left(\frac{\varepsilon_p}{\varepsilon_r} \right) = -3.15552 + \log \beta_{r_1} + 1.734 \beta_{r_2} \log T + 0.39937 \beta_{r_3} \log N$$

ε_p = plastic strain

ε_r = resilient strain

T = layer temperature (deg F)

N = no of load repetition

$\beta_{r_1}, \beta_{r_2}, \beta_{r_3}$ = calibration factors

Field Calibration Factors

AC-Rutting (β_{r_1} Calibration Factor)

$$\beta_{r_1} = \beta'_{r_1} * \beta''_{r_1}$$

β'_{r_1} = Polynomial Calibration Adjustment for ε_p as a function of depth –
accounts for confining pressure changes with depth.

β''_{r_1} = 1.4 (Calibration Adjustment for ε_p testing at all depths).

998 MnROAD Forensic

June
Cells 4,20,23

August
Cells 16,17,18,19,22

All Mainline Cells

2002
Design Guide
NCHRP 1-37A



1998 Mn/ROAD - Mainline Forensic (inches)

Cell	Surface Thick	Asphalt Binder	Surface Rut	Lift & Layer Deformation							
				1	2	3	4	5	Base	Subgra	
4	9.1	120-150	.41 *	.13	.24	0	0	---	0	0	
16	8.2	AC-20	.21	.07	.14	0	0	---	0	0	
17	8.2	AC-20	.30	.15	.15	0	0	---	0	0	
18	8.2	AC-20	.24	.09	.15	0	0	---	0	0	
19	8.1	AC-20	.24	.06	.04	.07	.07	---	0	0	
20	7.9	120-150	.48	.24	.10	.12	.02	---	0	0	
22	7.4	120-150	.30 *	.12	.06	.06	0	---	0	0	
23	9.2	120-150	.48 *	.26	.05	.04	.10	0	0	0	

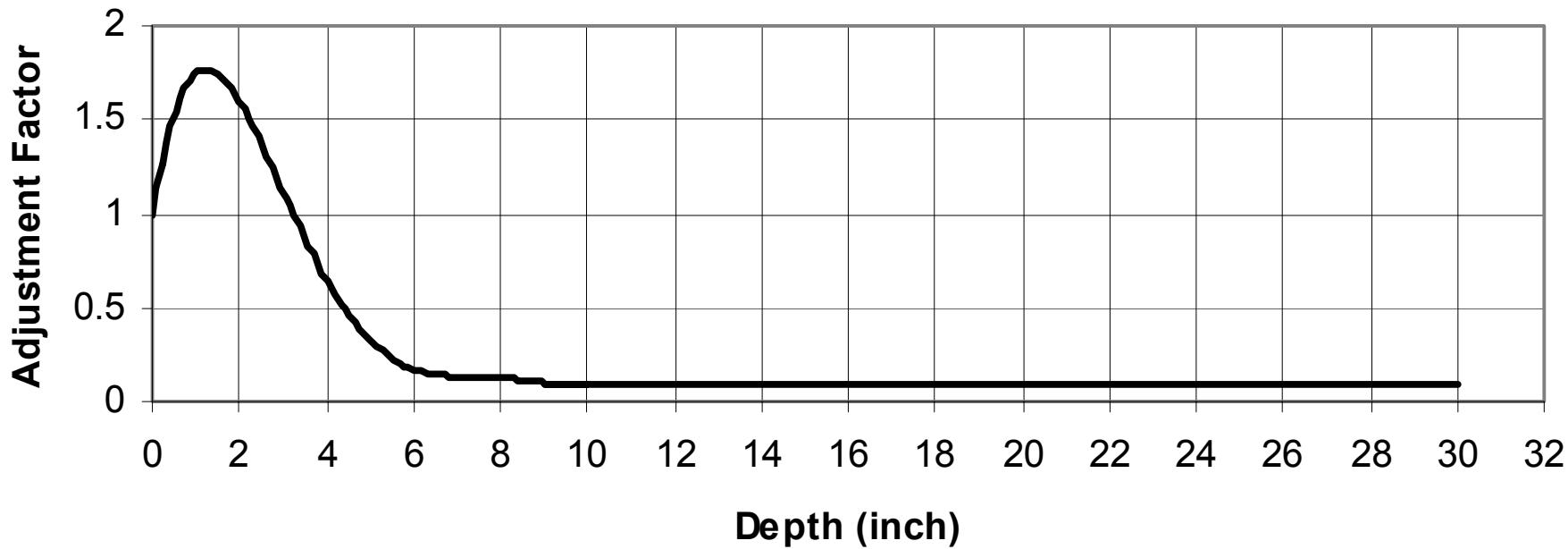
2002

Design Guide

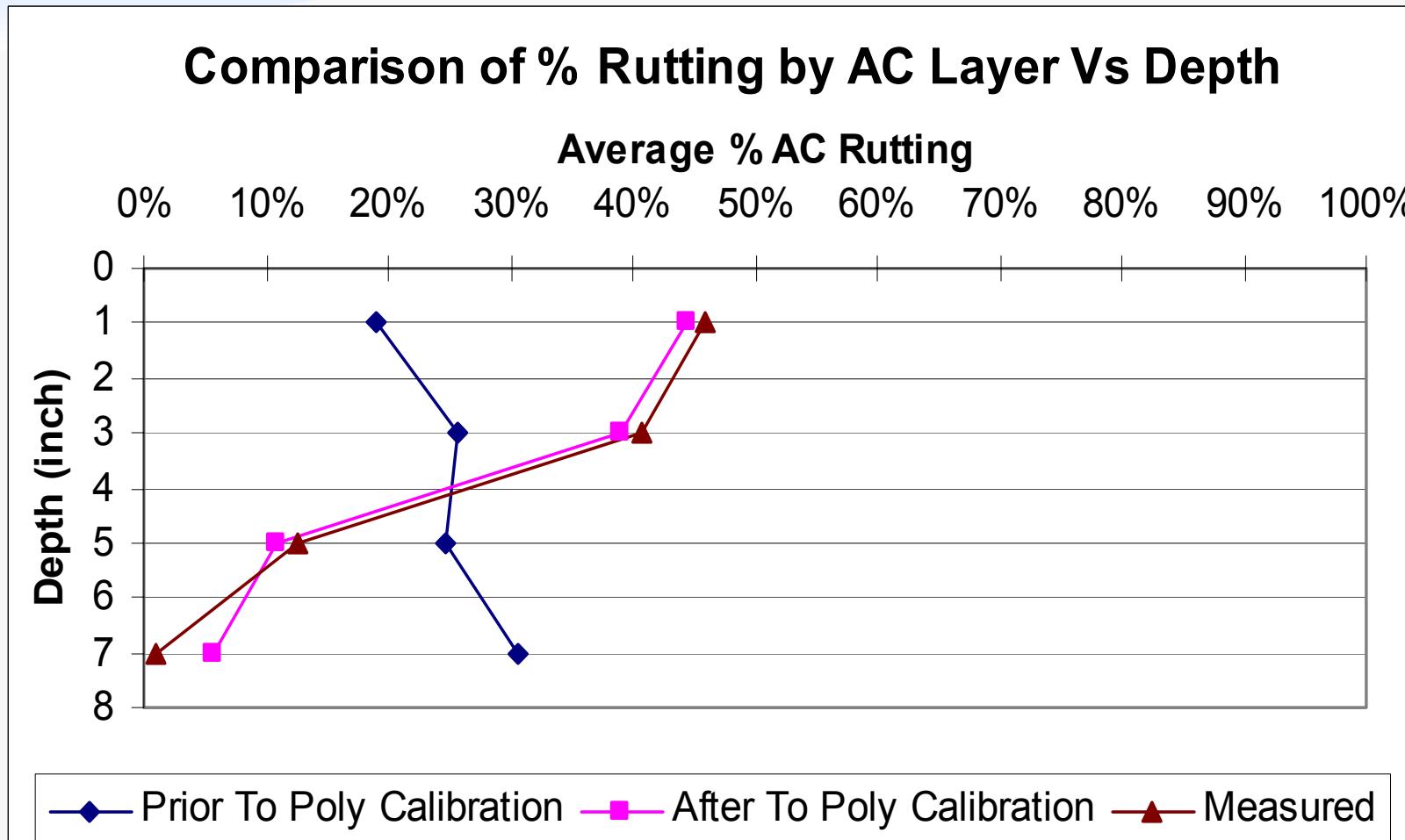
AC Depth Polynomial Calibration Function

$$y = 0.000459x^5 - 0.01470x^4 + 0.17336x^3 - 0.88108x^2 + 1.49071x + 0.97774$$

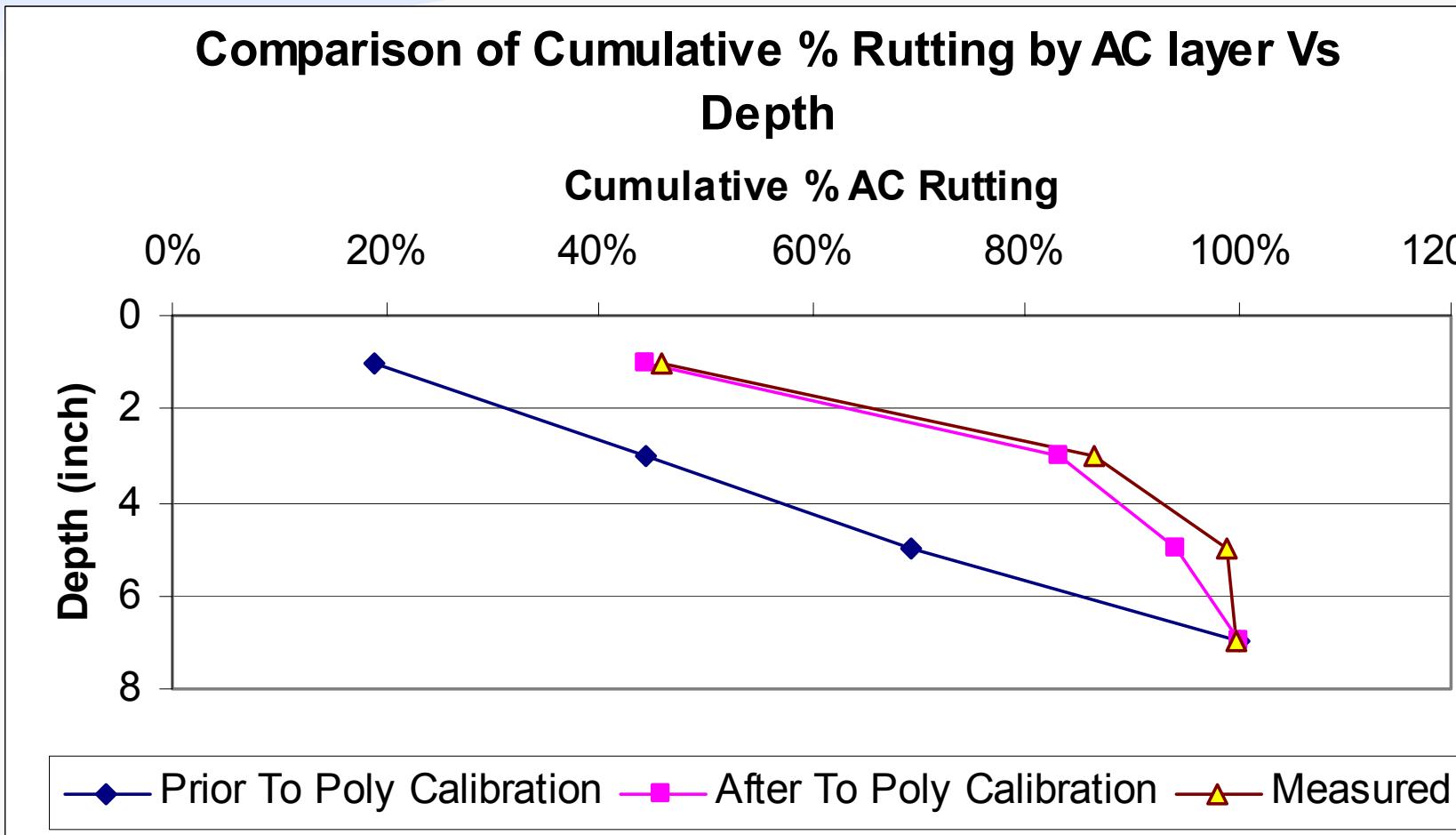
For Depth $\geq 9"$; $y=0.1$



Comparison of Polynomial Model Calibration to Measured AC Rutting



Comparison of Polynomial Model Calibration to Measured AC Rutting



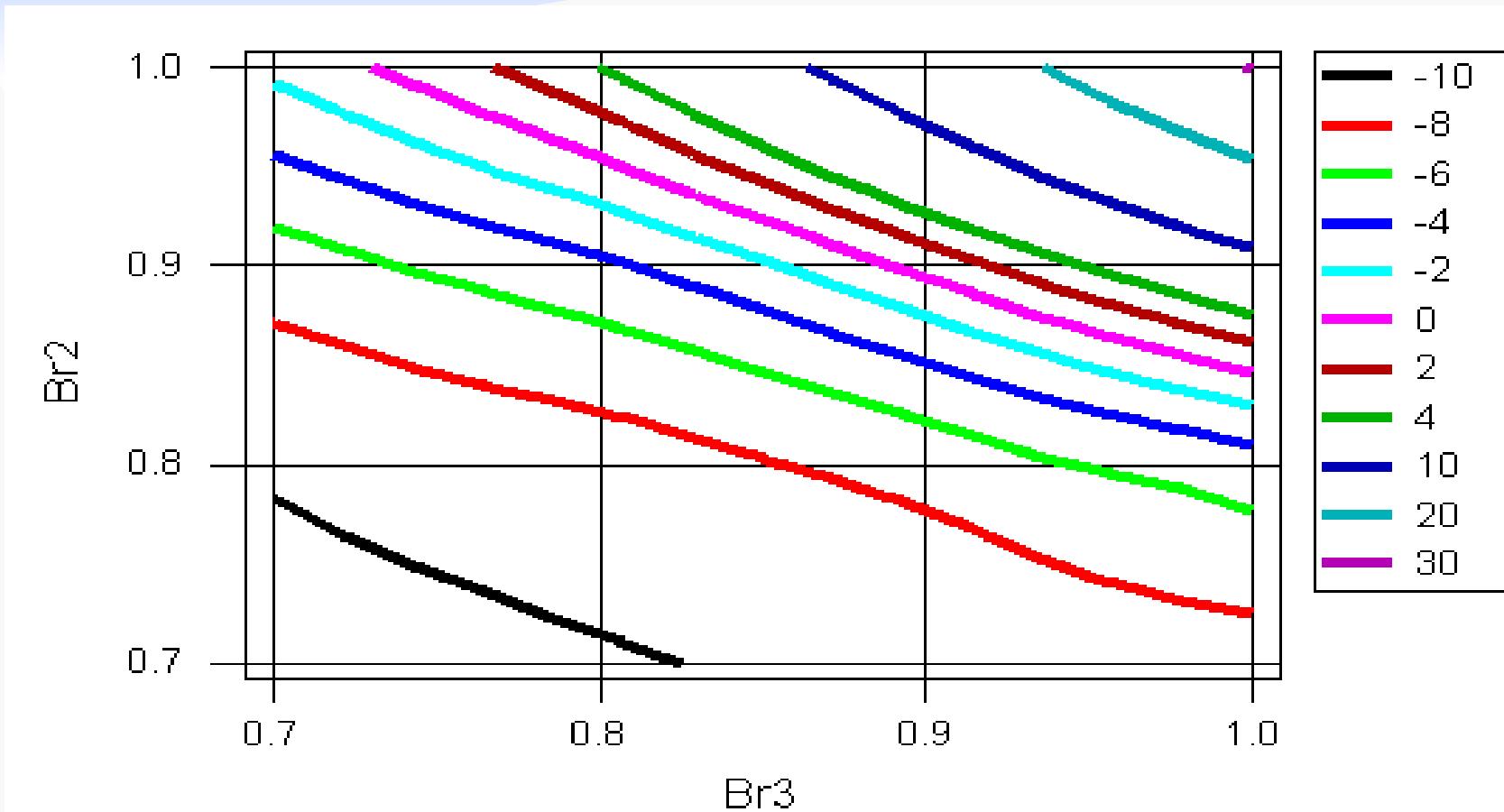
Field Calibration

Difference in Total RD

Run	Granular Material	Fine Grained Material	Br1	Br2	Br3	Total Diff. (Pred -Meas)
0	2	0.5	1	1	1	24.336
1	2	0.5	1.4	1	1	30.322
2	2	0.5	1.4	1	0.85	8.544
3	2	0.5	1.4	1	0.7	-1.511
4	2	0.5	1.4	0.85	1	0.494
5	2	0.5	1.4	0.85	0.85	-5.776
6	2	0.5	1.4	0.85	0.7	-8.658
7	2	0.5	1.4	0.7	1	-8.847
8	2	0.5	1.4	0.7	0.85	-9.857
9	2	0.5	1.4	0.7	0.7	-10.686

Field Calibration

Contour of Difference in Total RD

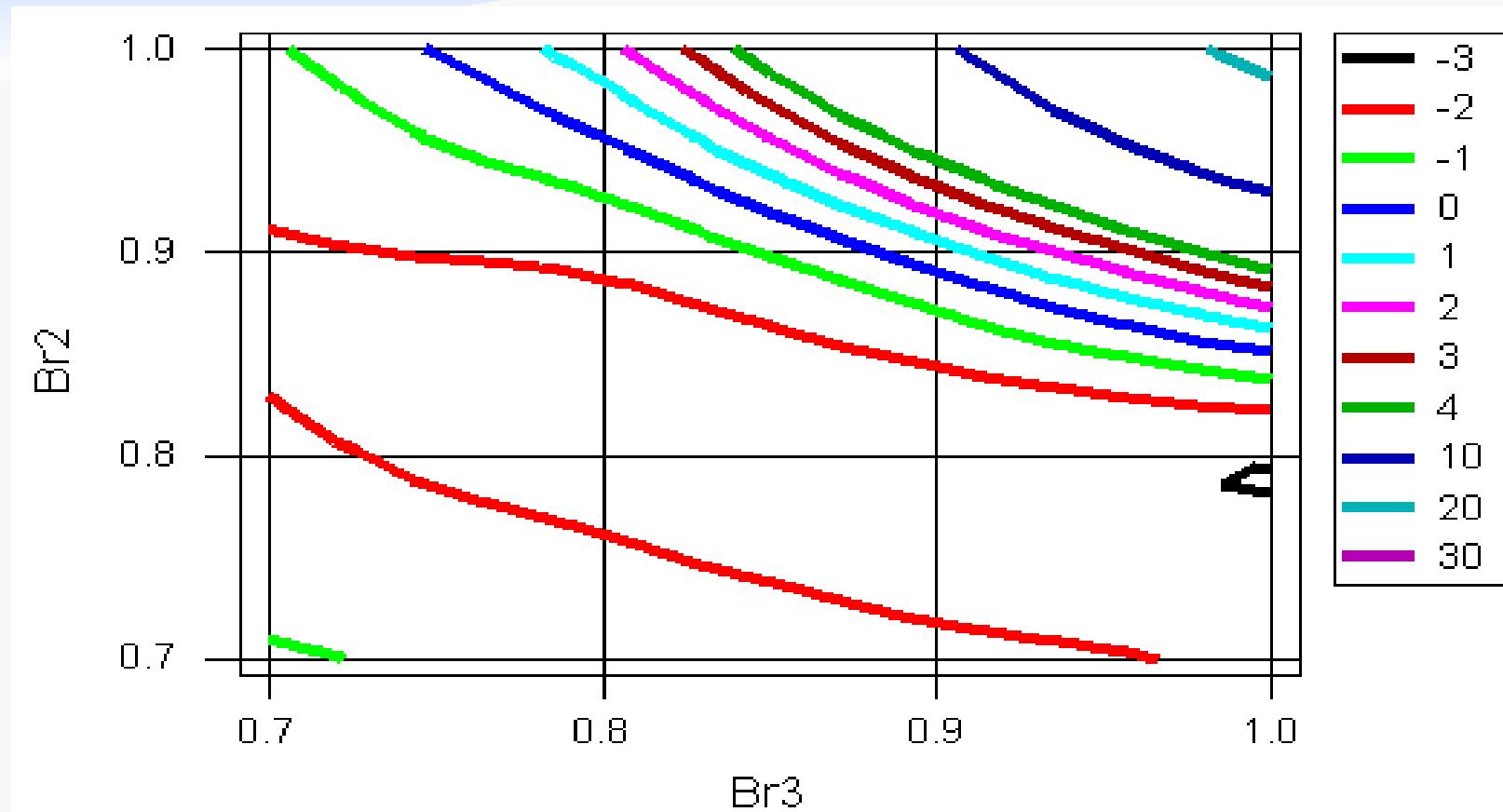


Field Calibration

Difference in AC RD

Run	Granular Material	Fine Grained Material	Br1	Br2	Br3	AC Diff. (Pred - Meas)
0	2	0.5	1	1	1	17.747
1	2	0.5	1.4	1	1	22.524
2	2	0.5	1.4	1	0.85	4.797
3	2	0.5	1.4	1	0.7	-1.115
4	2	0.5	1.4	0.85	1	-0.054
5	2	0.5	1.4	0.85	0.85	-2.257
6	2	0.5	1.4	0.85	0.7	-2.066
7	2	0.5	1.4	0.7	1	-2.187
8	2	0.5	1.4	0.7	0.85	-1.536
9	2	0.5	1.4	0.7	0.7	-0.911

Field Calibration Contour of Difference in AC RD



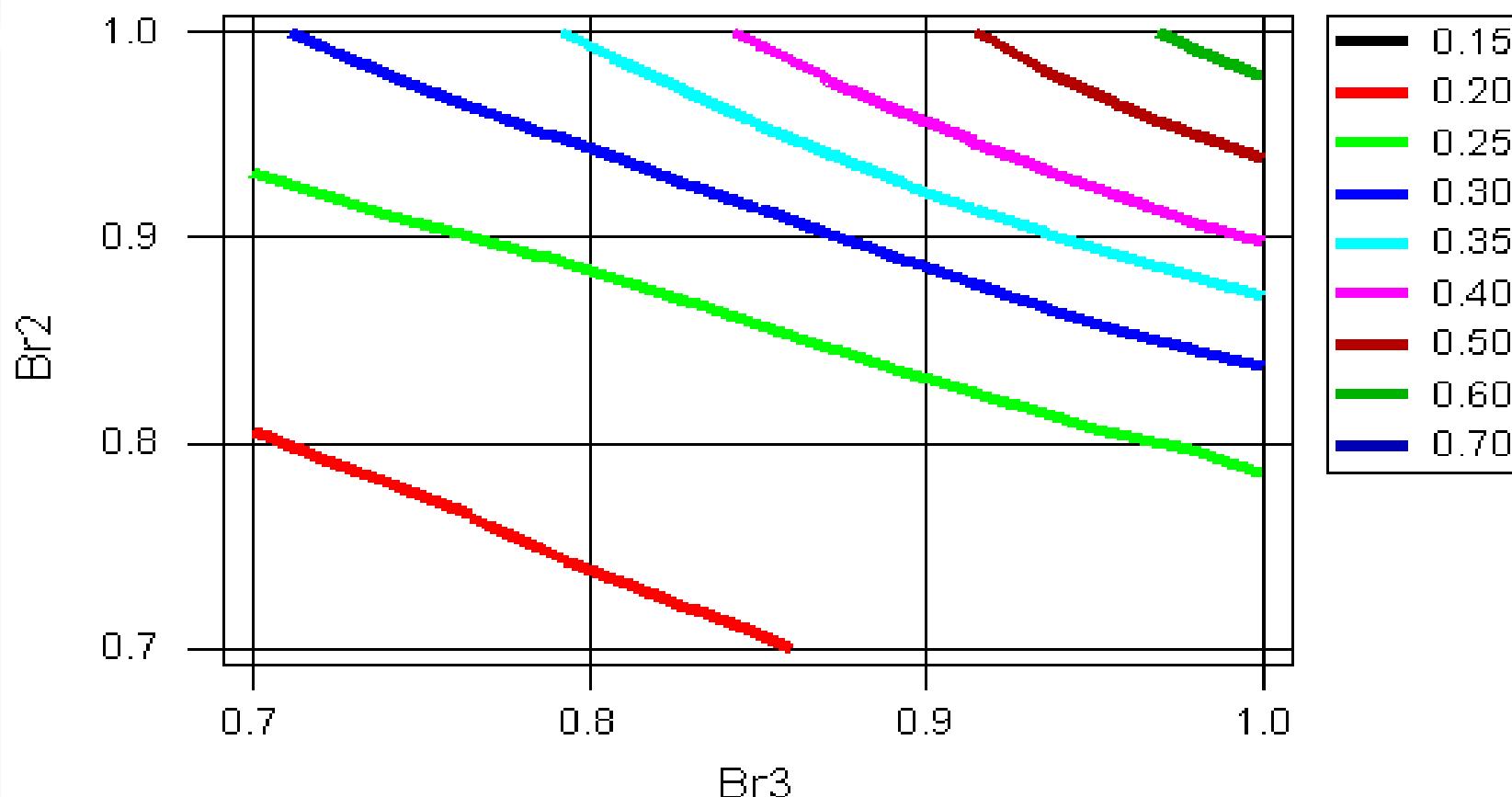
Field Calibration

Total RD After 10 Years

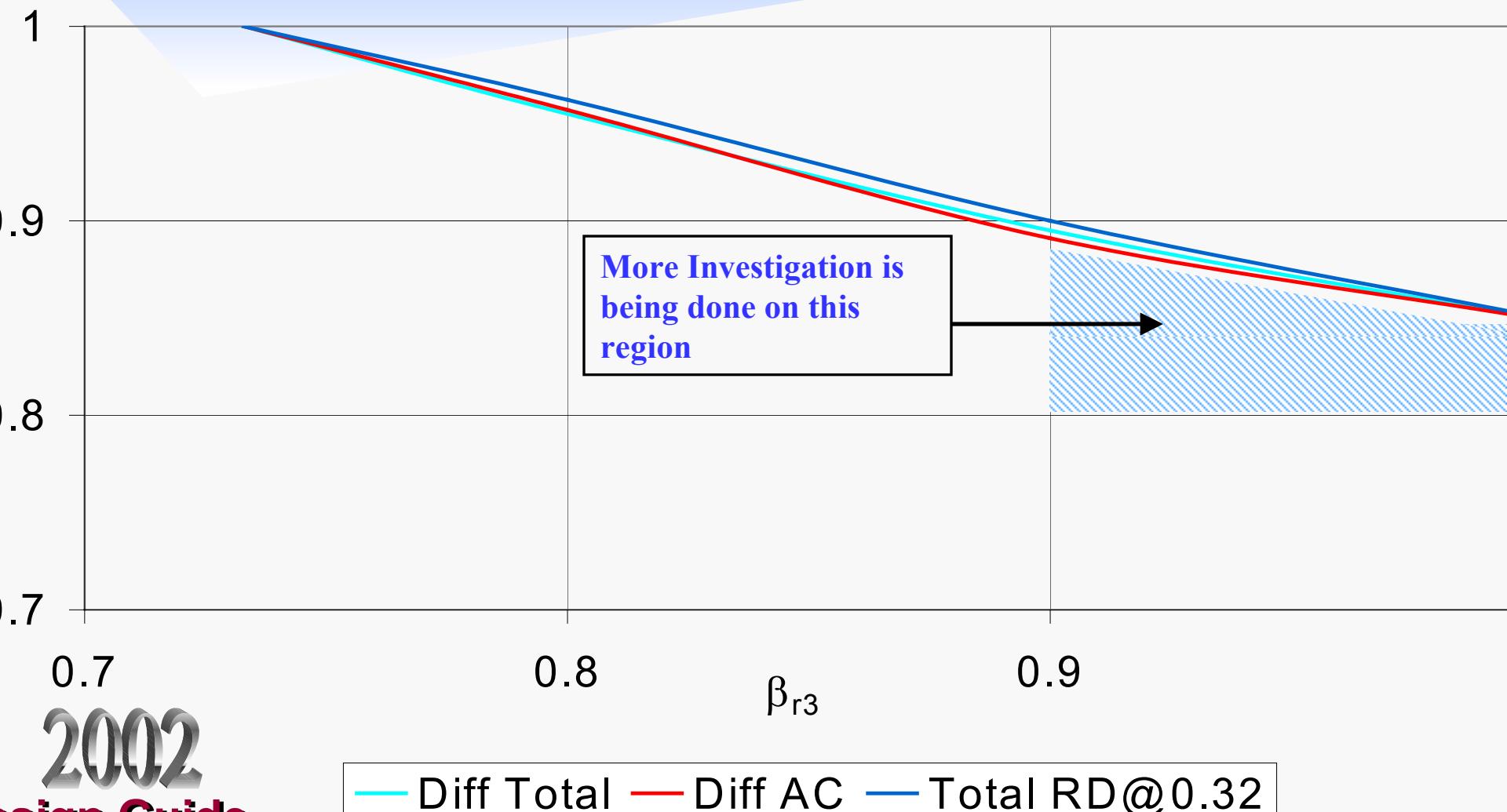
Run	Granular Material	Fine Grained Material	Br1	Br2	Br3	Avg Total
0	2	0.5	1	1	1	0.59
1	2	0.5	1.4	1	1	0.66
2	2	0.5	1.4	1	0.85	0.41
3	2	0.5	1.4	1	0.7	0.29
4	2	0.5	1.4	0.85	1	0.32
5	2	0.5	1.4	0.85	0.85	0.25
6	2	0.5	1.4	0.85	0.7	0.21
7	2	0.5	1.4	0.7	1	0.22
8	2	0.5	1.4	0.7	0.85	0.20
9	2	0.5	1.4	0.7	0.7	0.19

Field Calibration

Contour of Total RD After 10 Years



Comparison of Contours for Total RD Diff., AC RD Diff. And Total Pred. RD

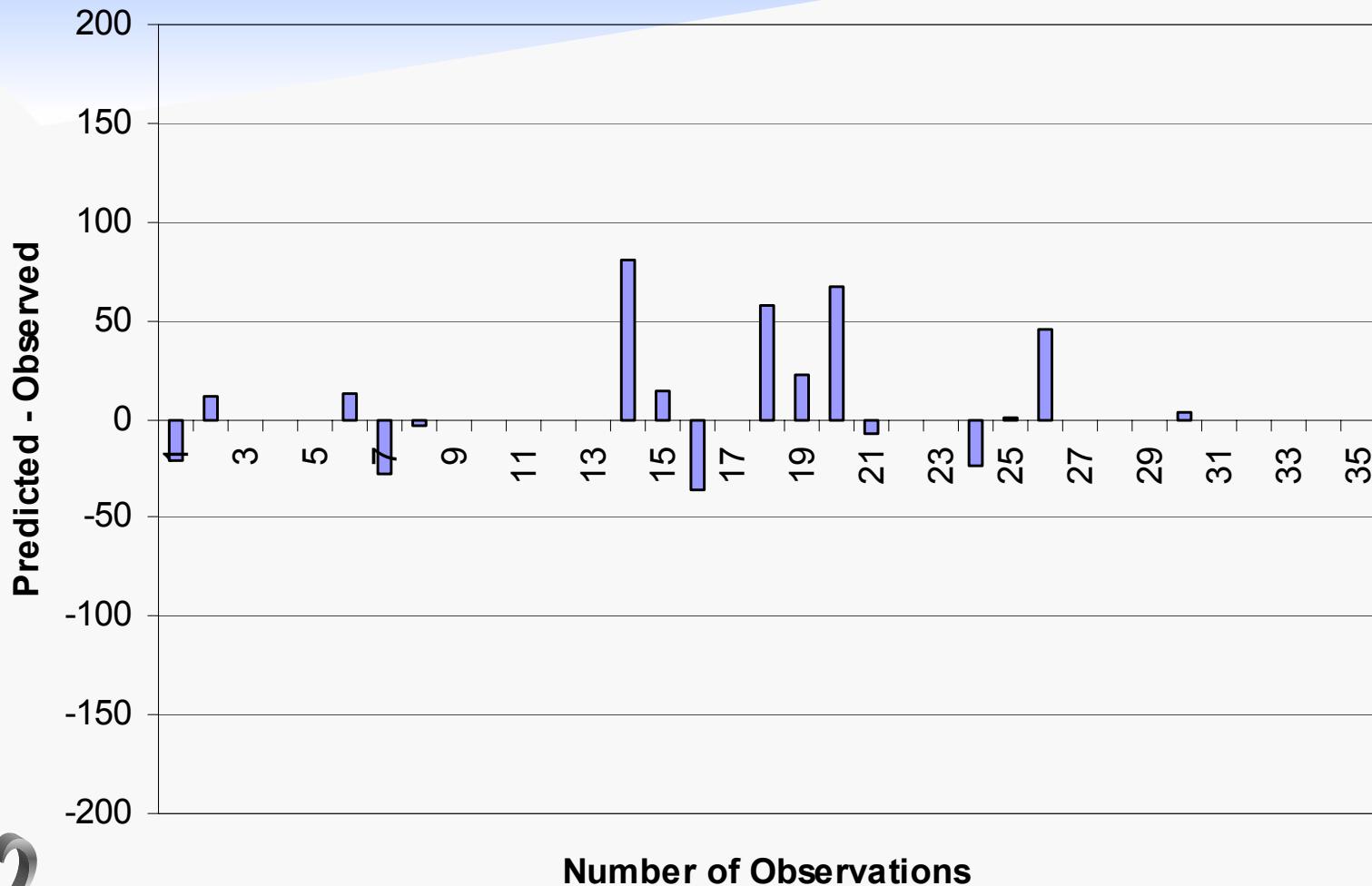


Thermal Fracture Predictions

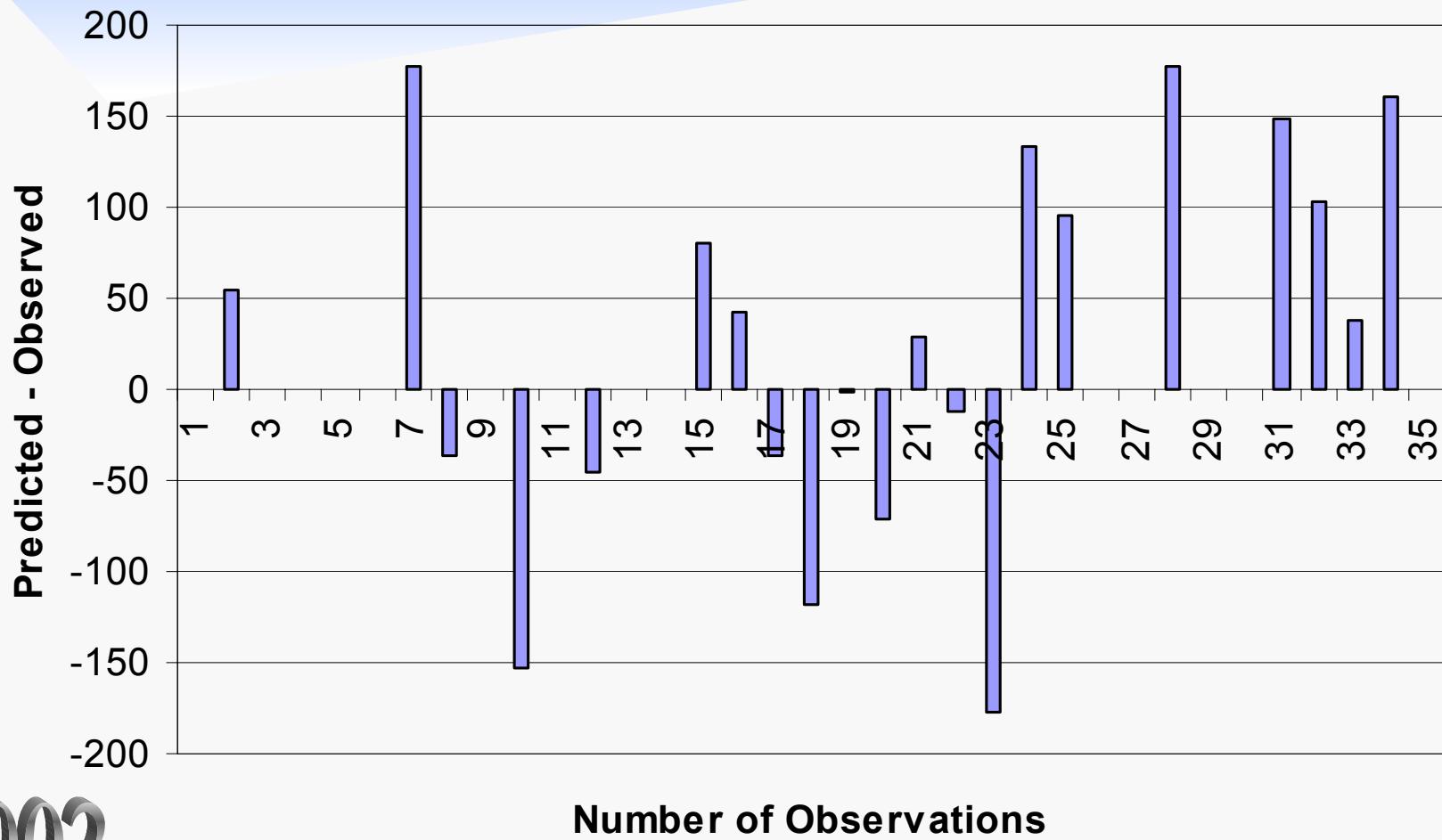
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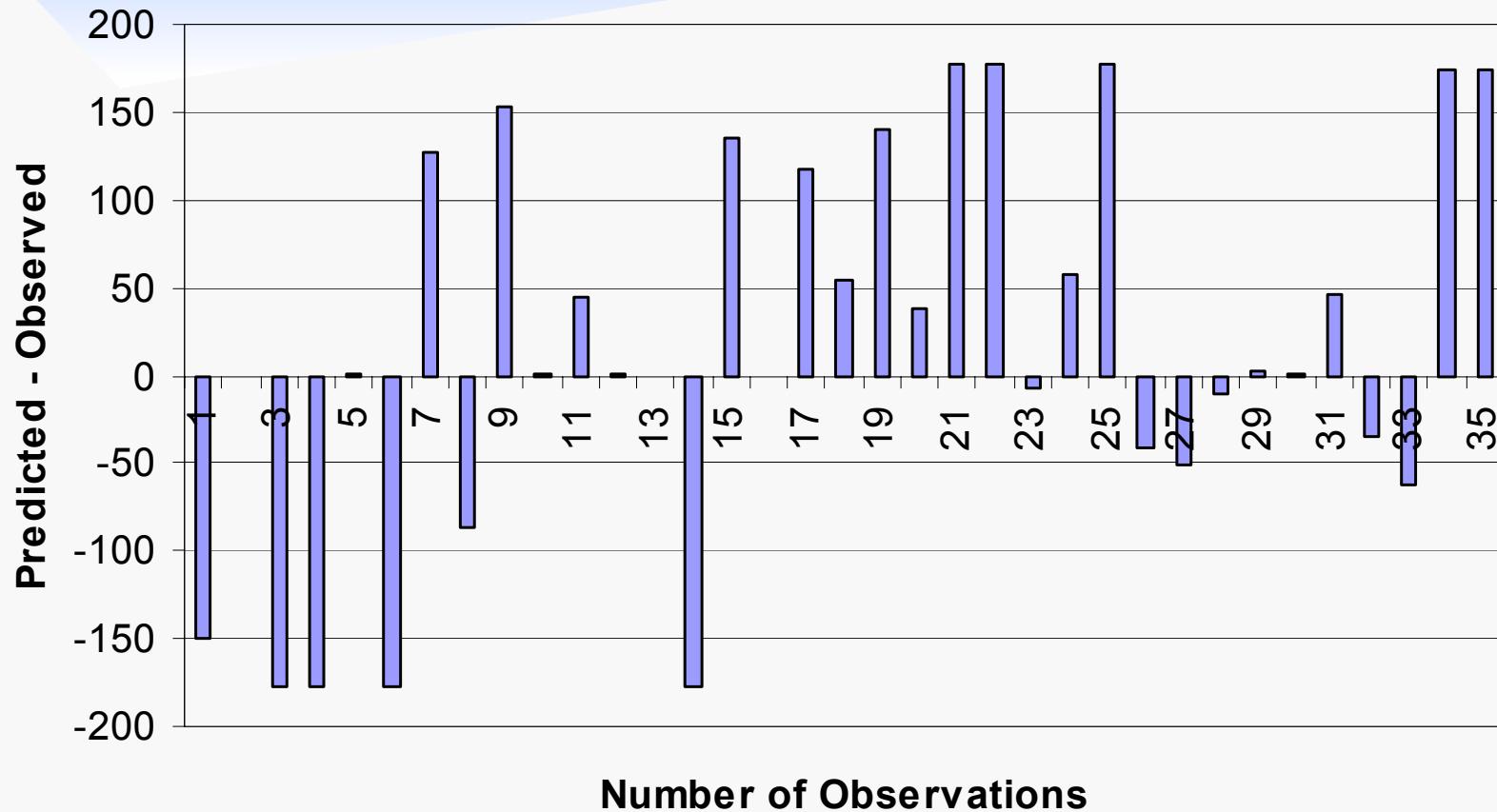
Prediction Error – Level 1 Analysis



Prediction Error – Level 2 Analysis



Prediction Error – Level 3 Analysis

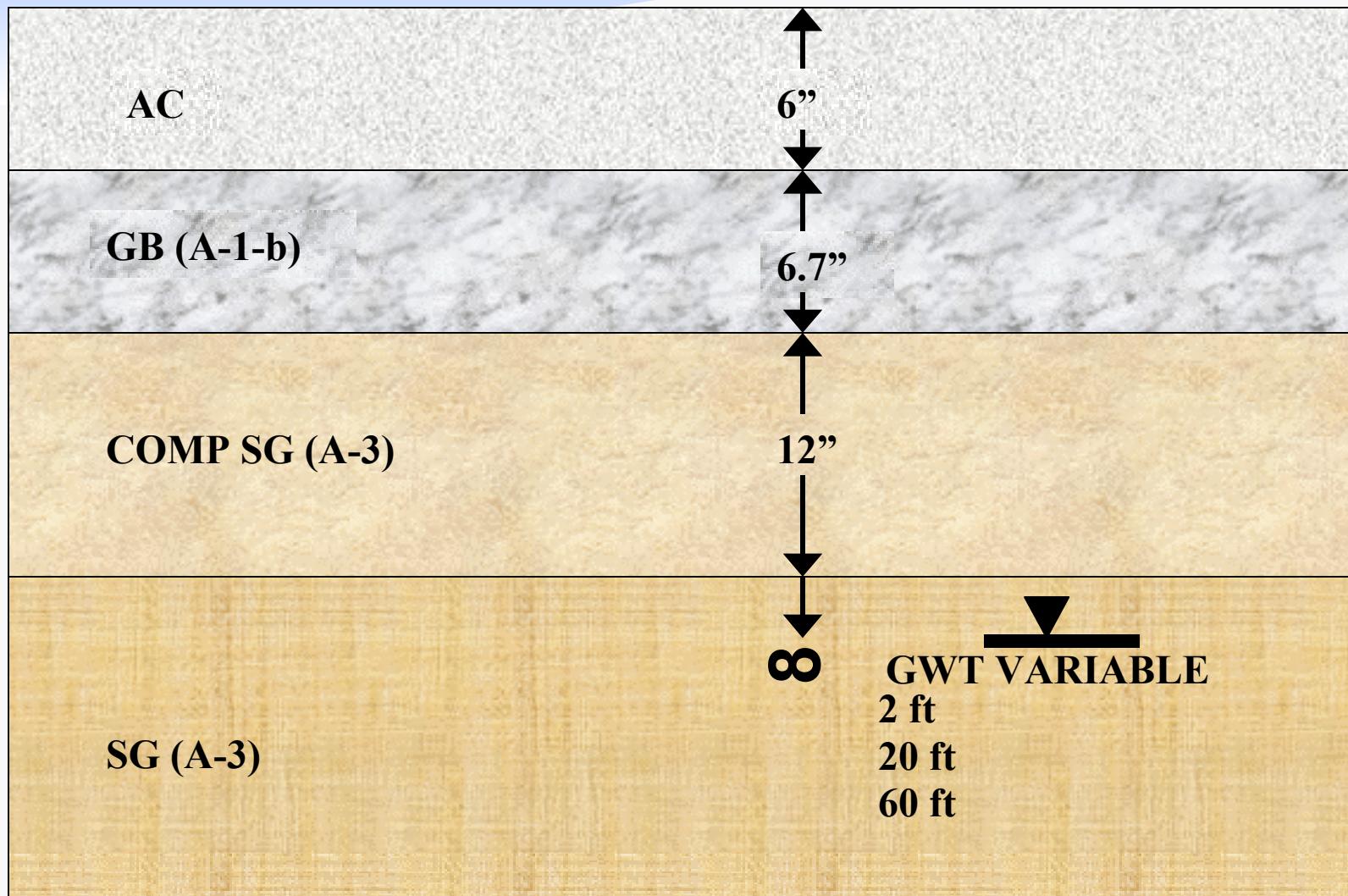


Statistical Summary

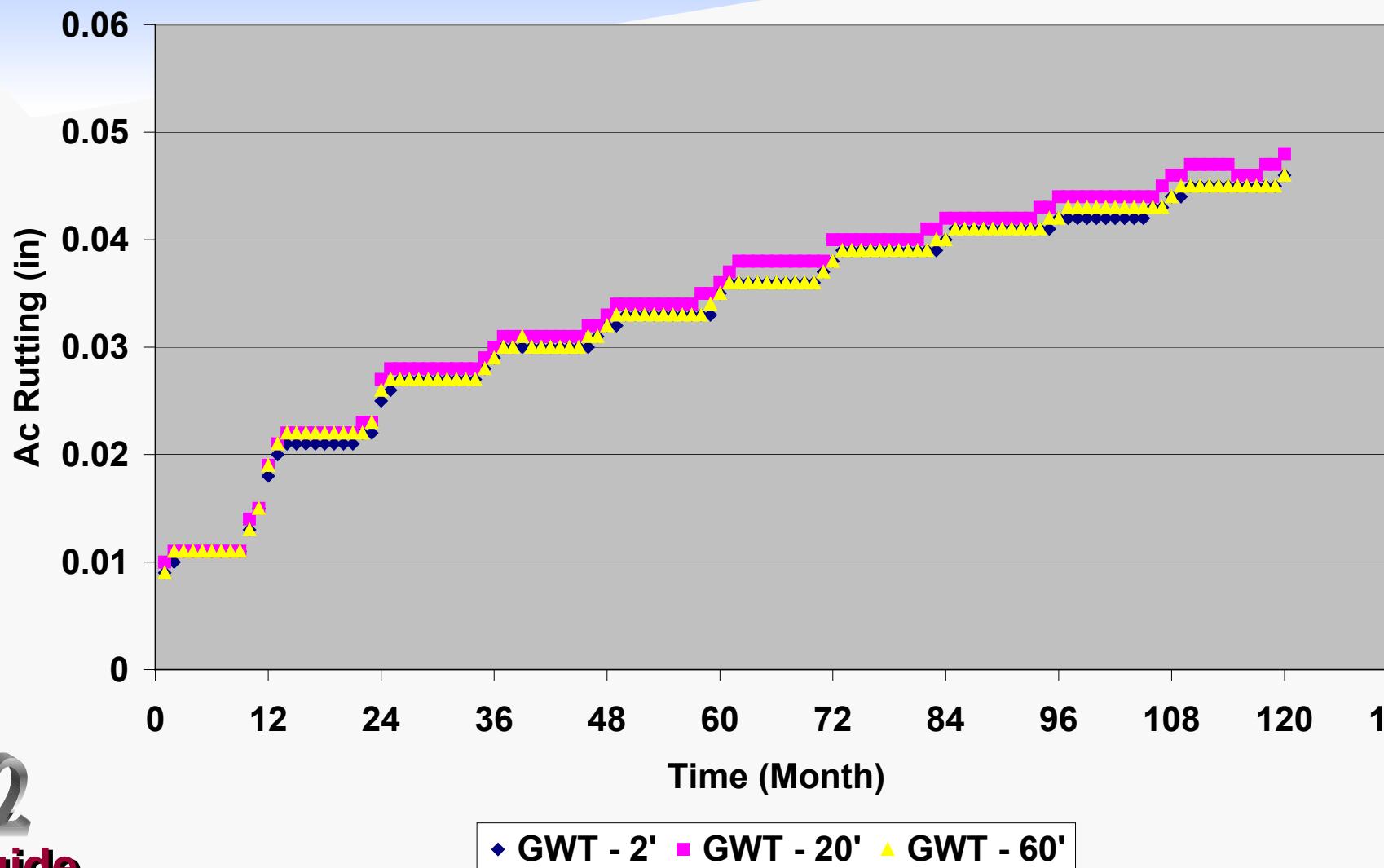
Statistical Parameter	Analysis Level		
	I	II	III
Average Prediction Error (Predicted – Observed)	5.6	16.8	35.3
Standard Deviation	23.9	82.2	98.4
R ²	0.93	0.18	0.03

Examples

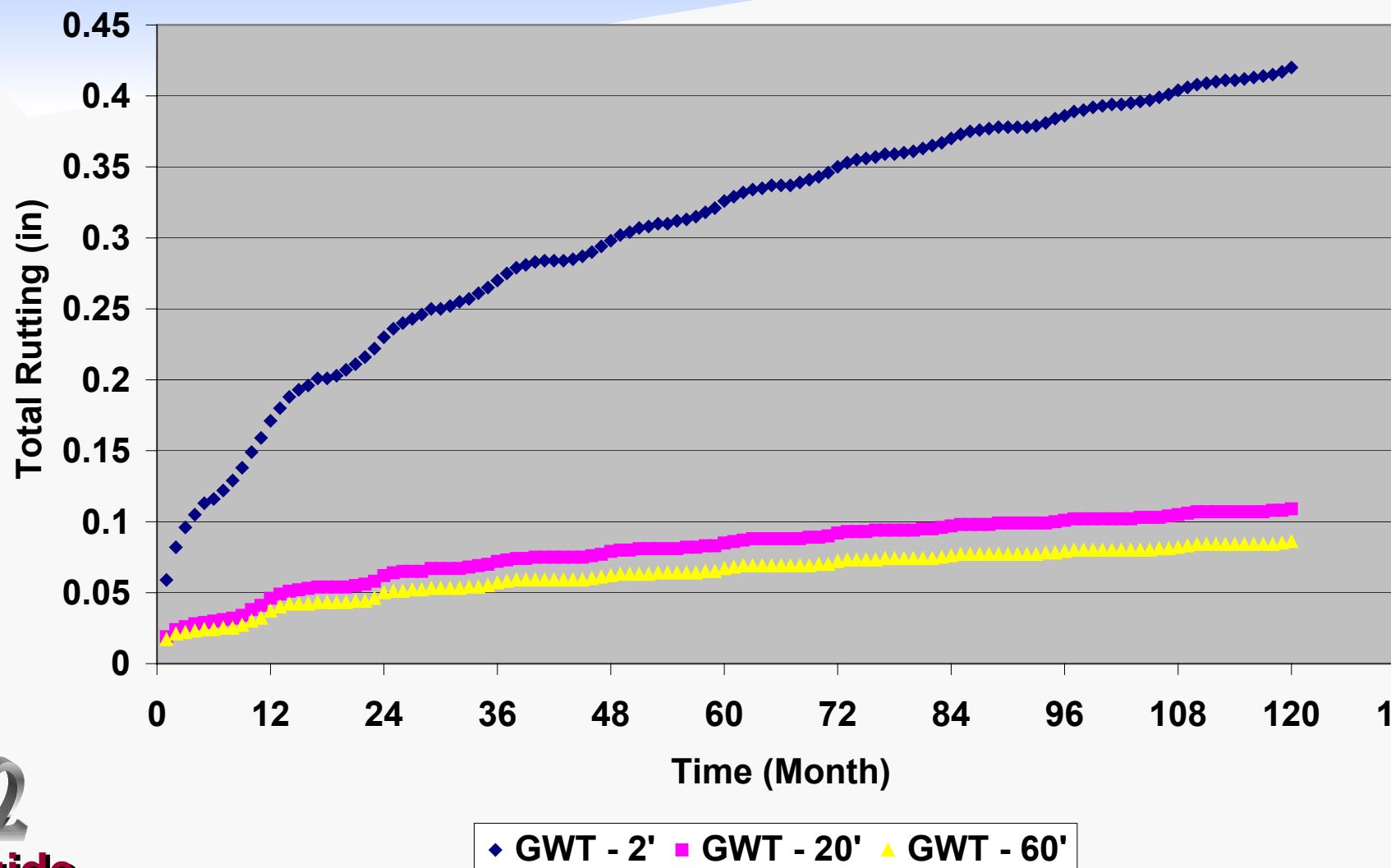
Example 1 – GWT Variation



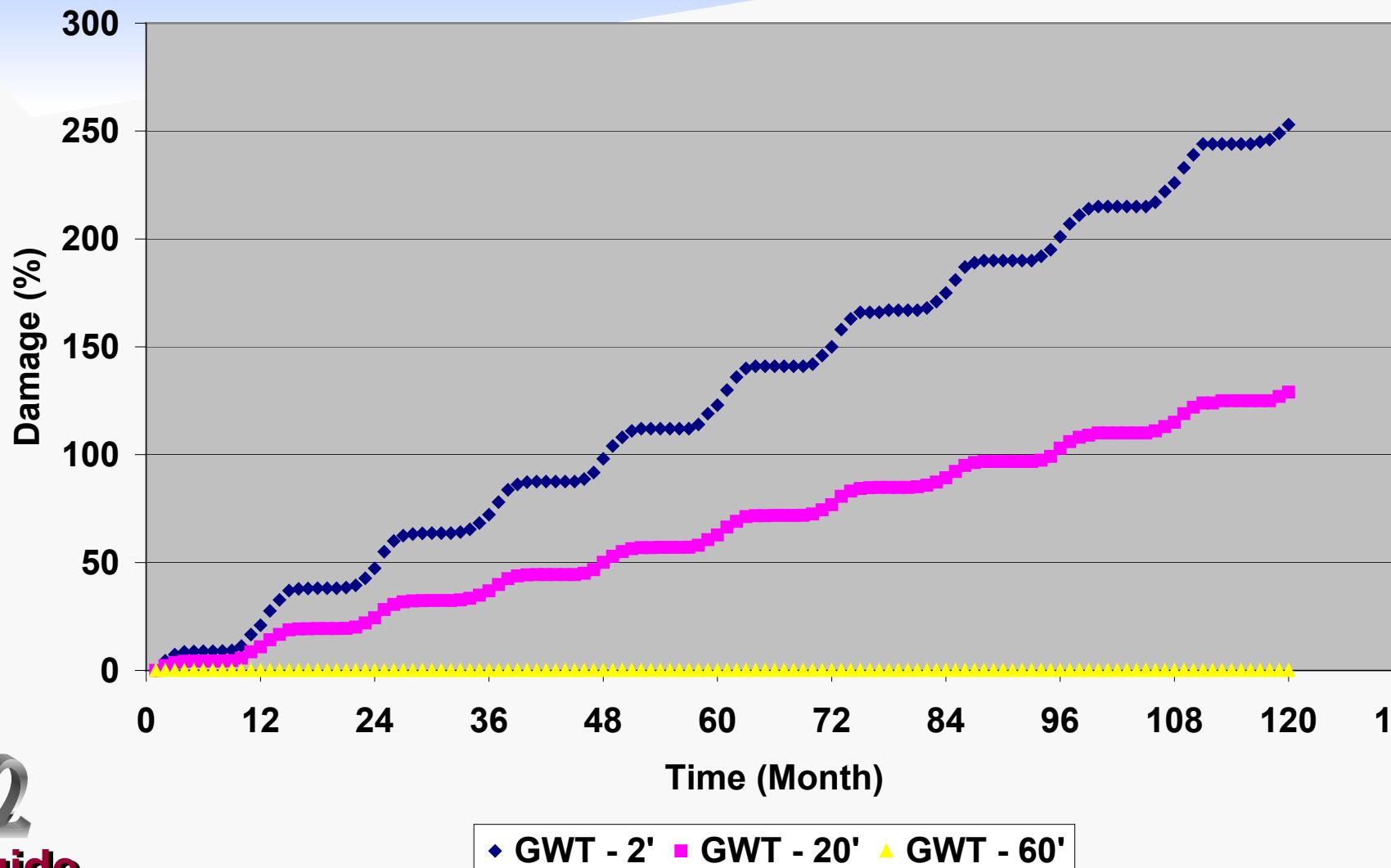
Rutting in Ac Layer



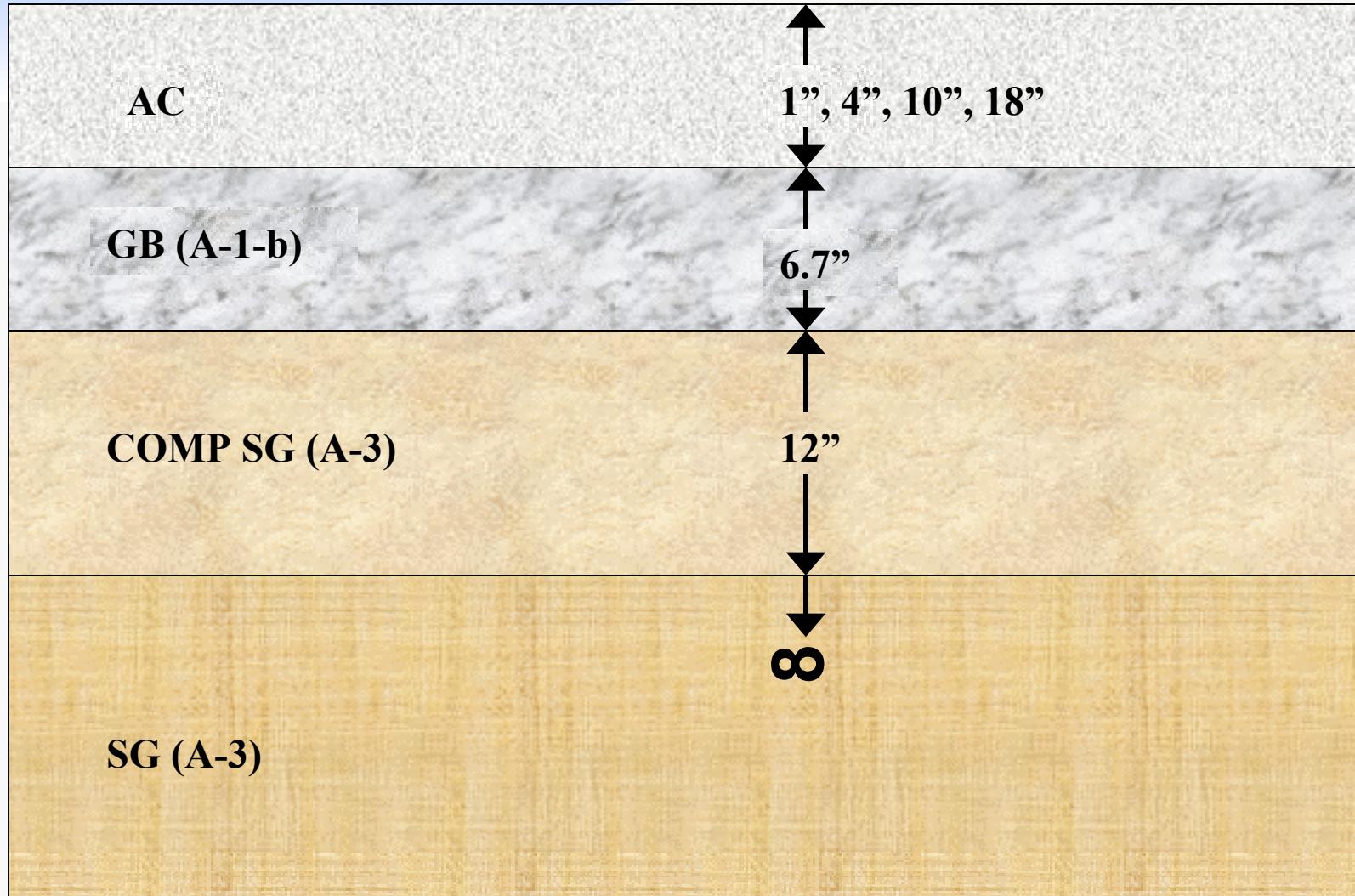
Total Rutting



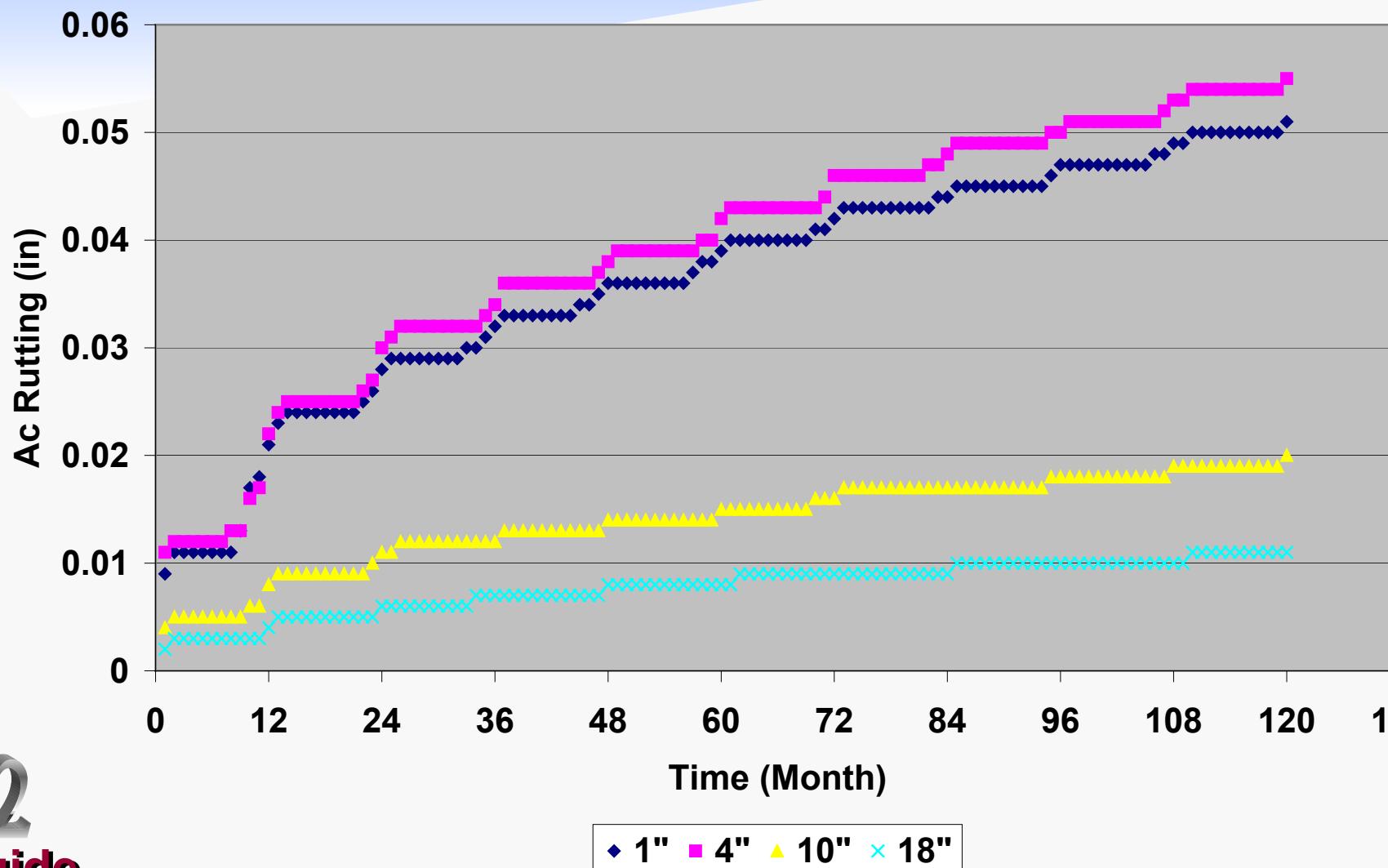
Bottom up % Damage (Alligator Cracking)



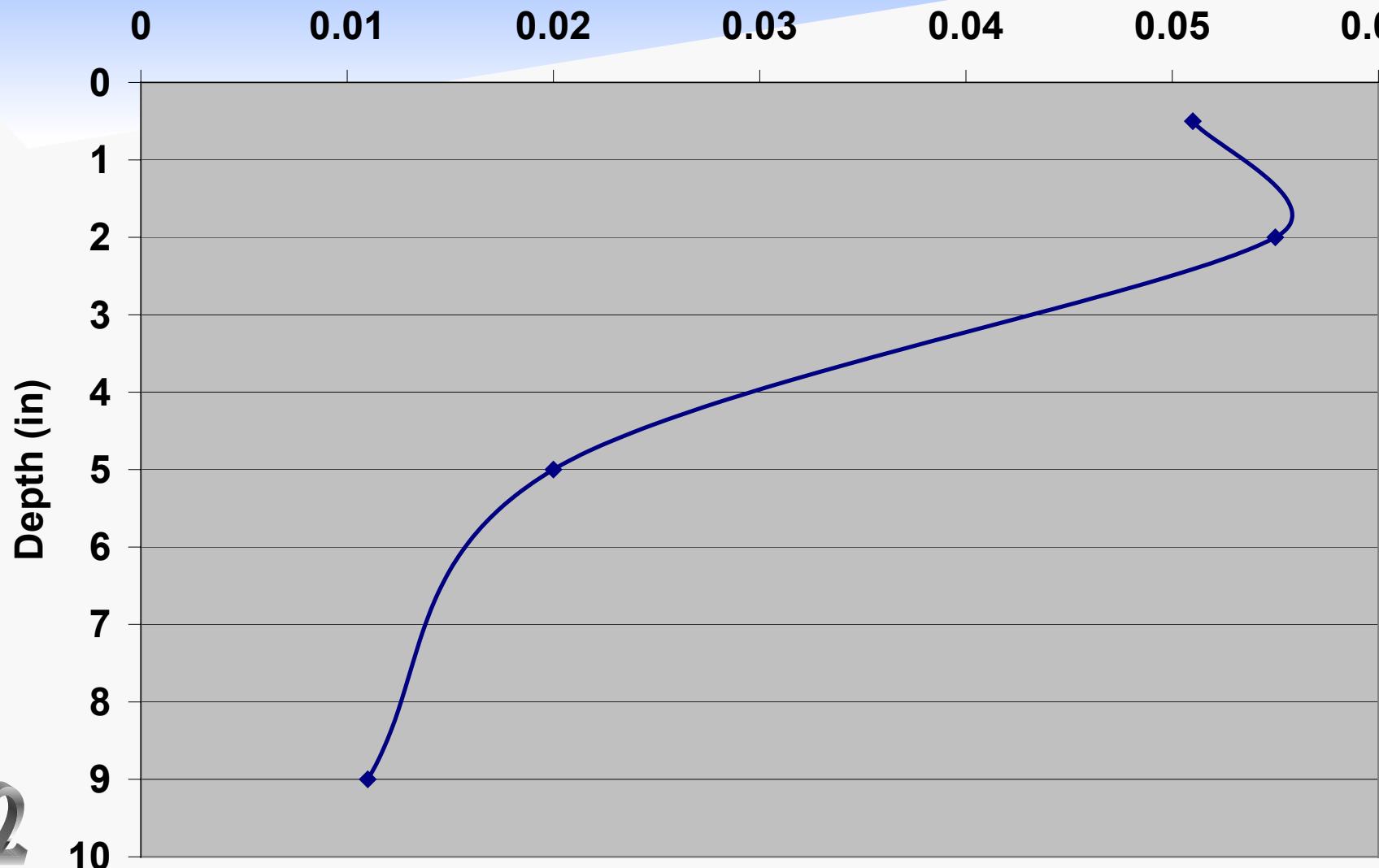
Example 2 – AC Thickness Variation



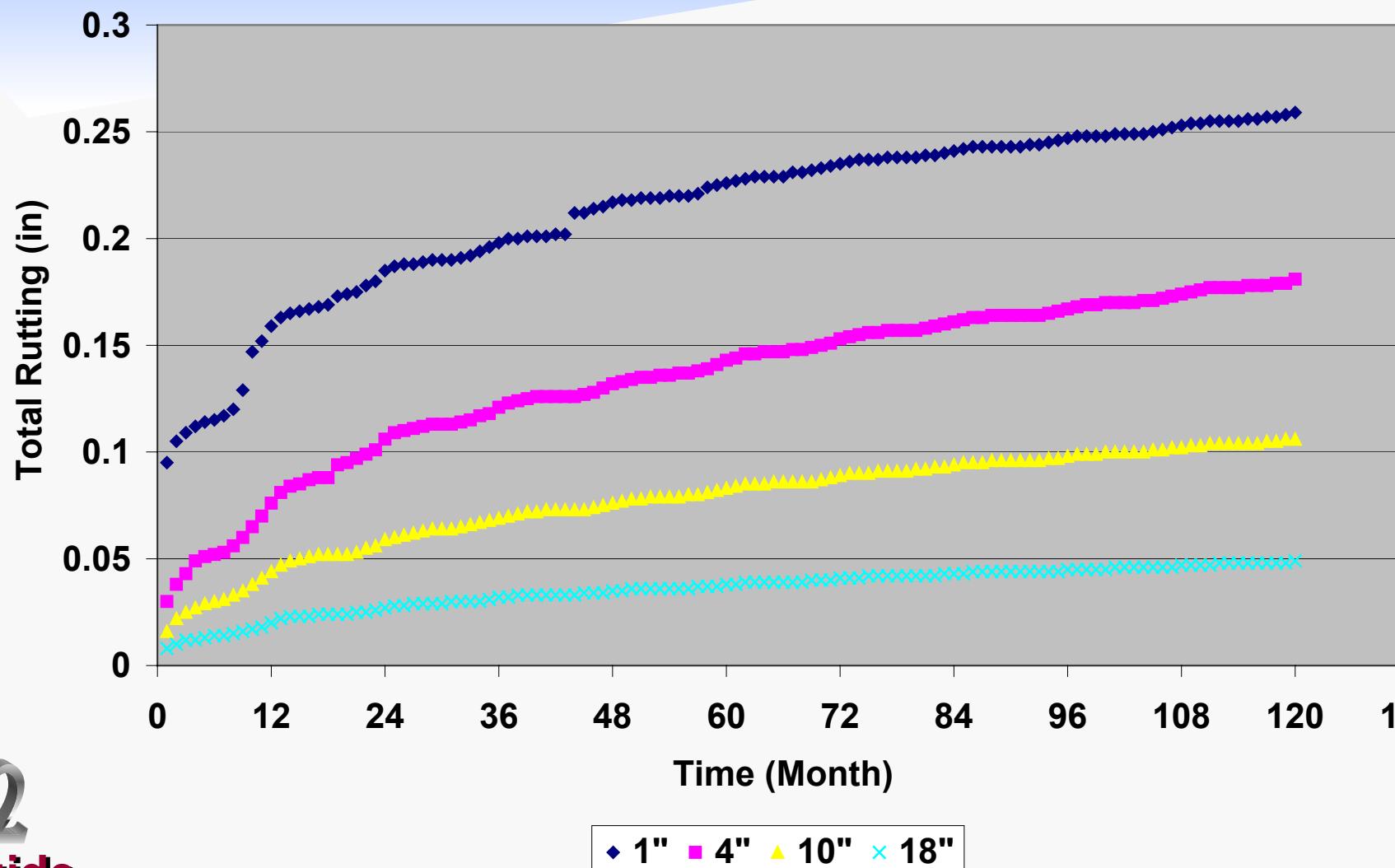
Rutting in Ac Layer



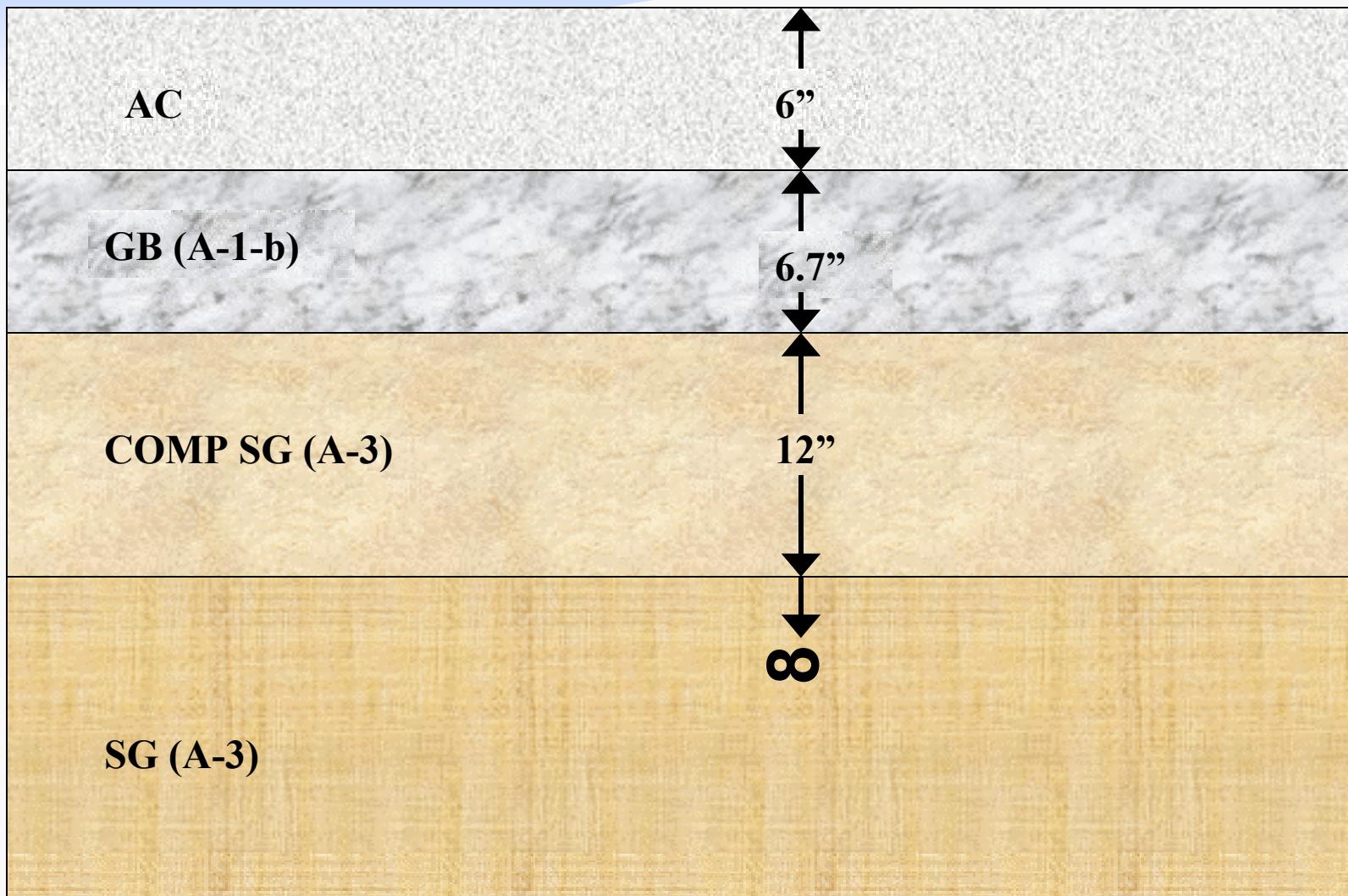
Ac Rutting (in)



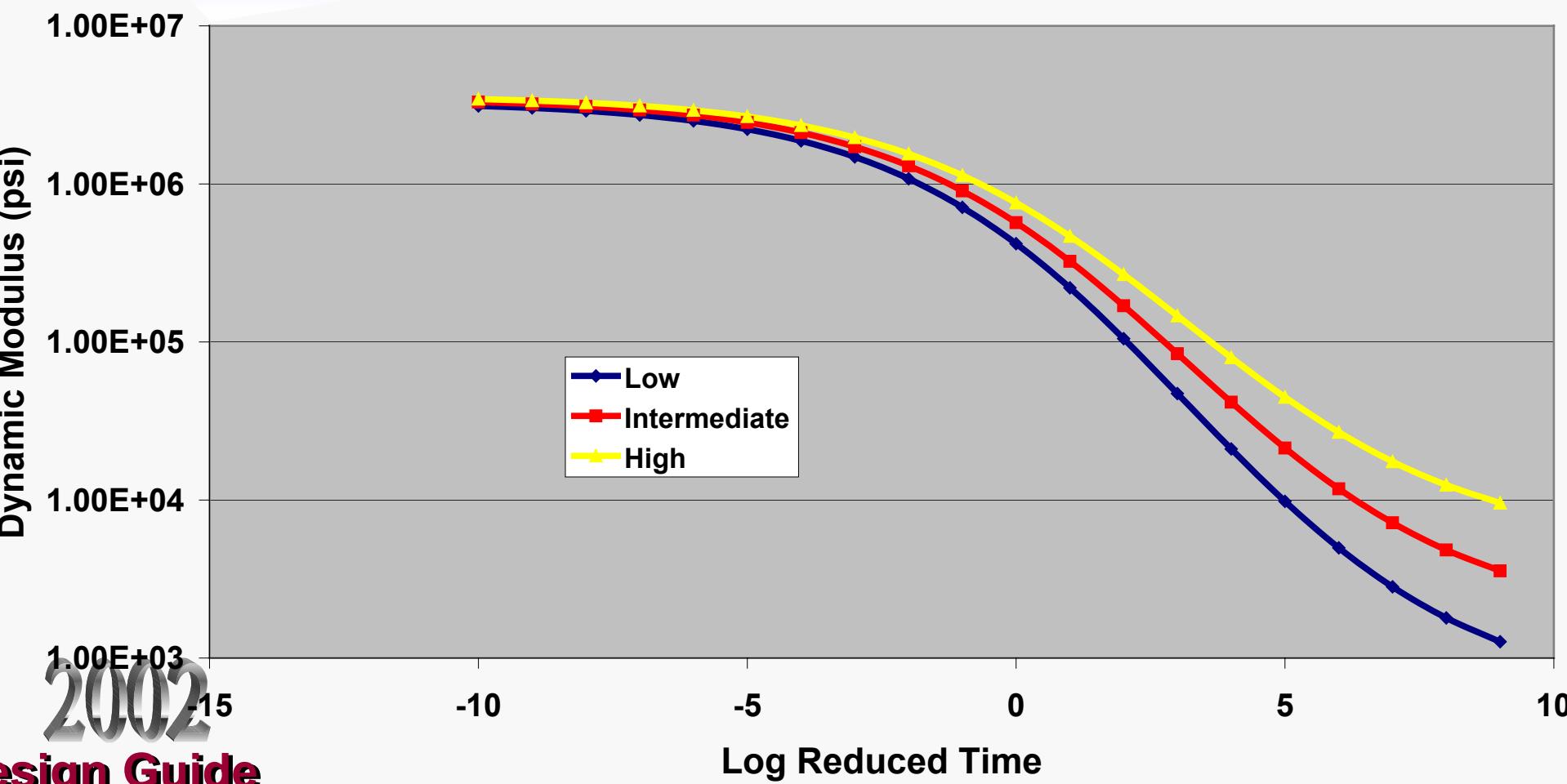
Total Rutting



Example 3 – AC Master Curves



Master Curves for Three Different Mixes

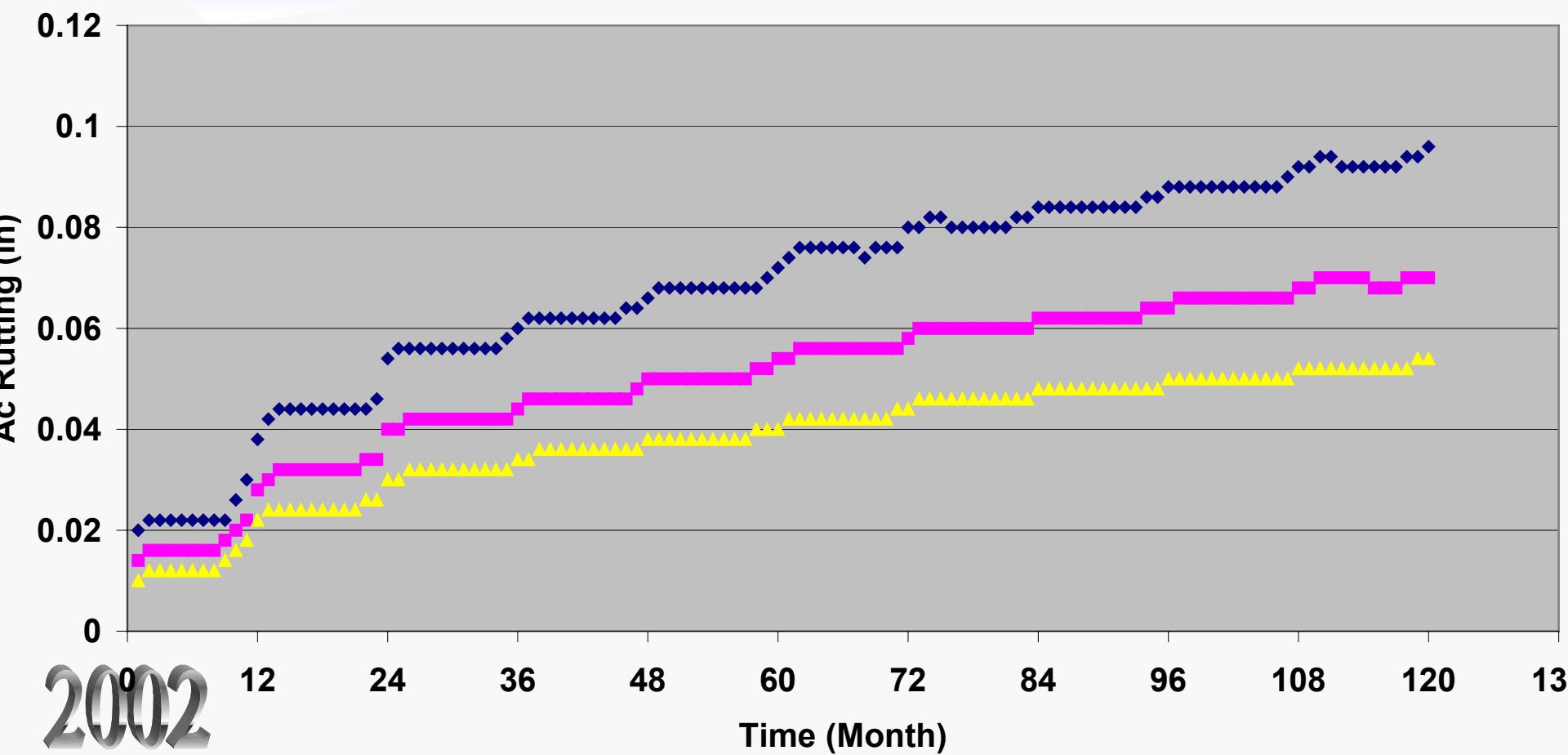


2002

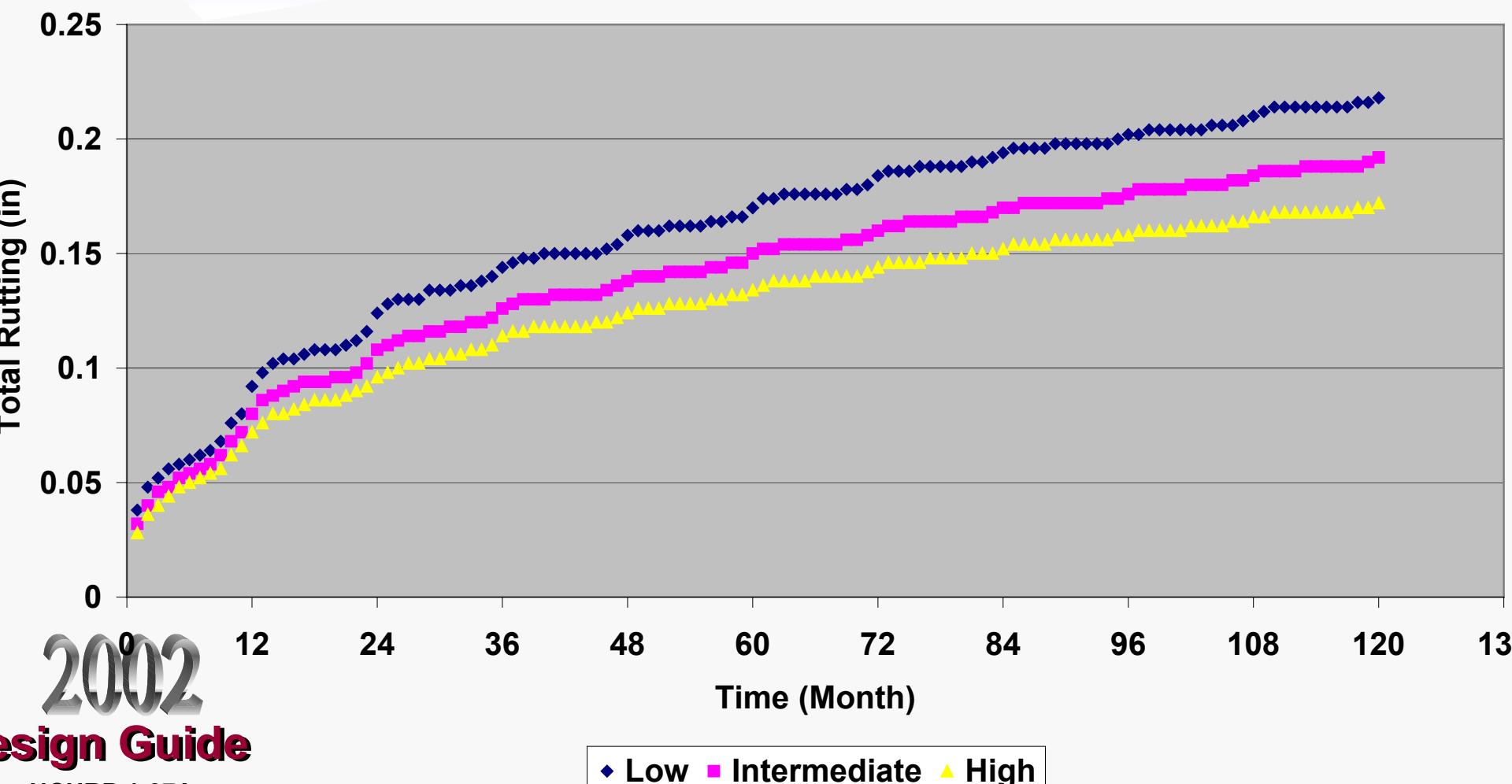
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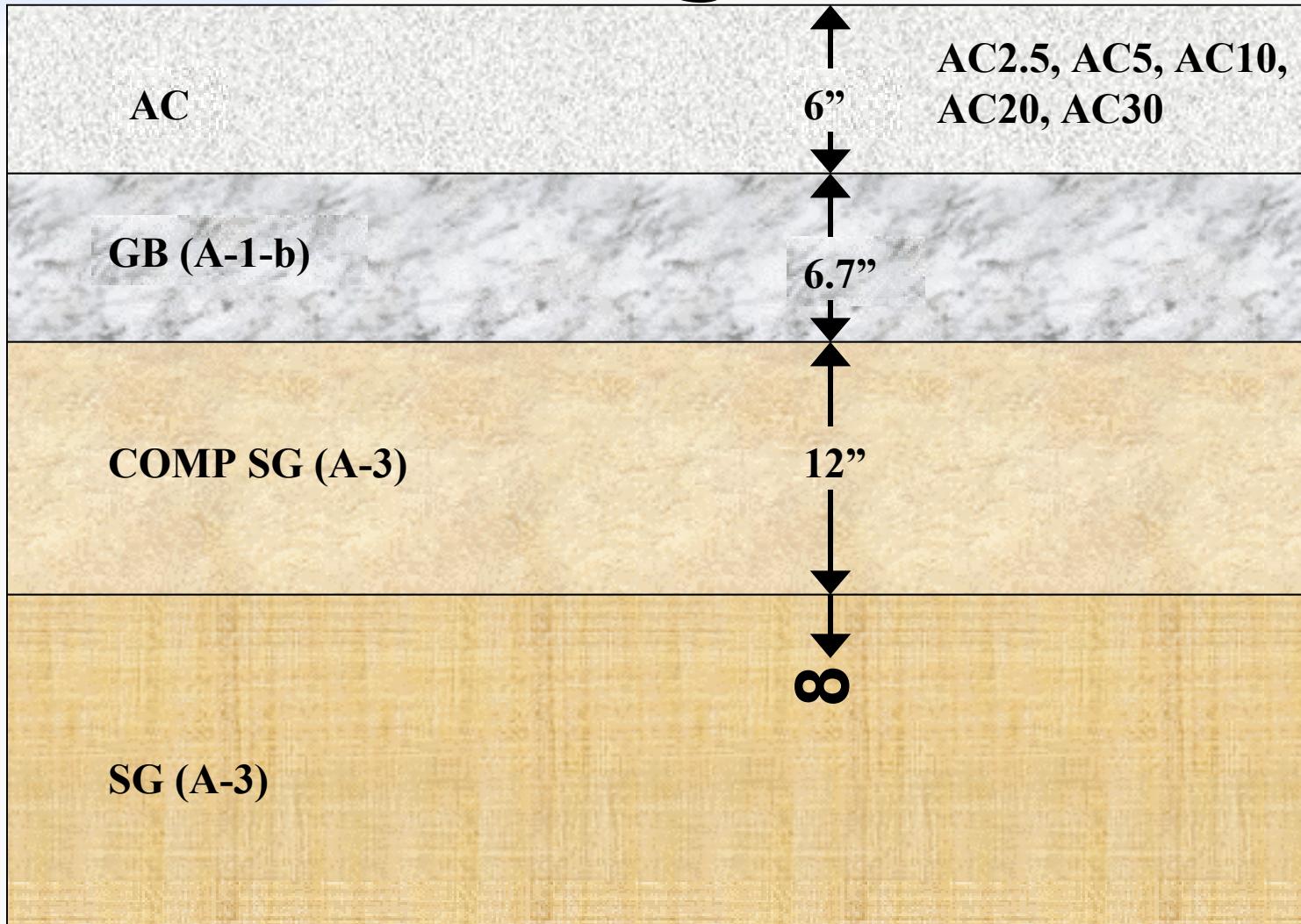
Rutting in Ac Layer For Various Mixes



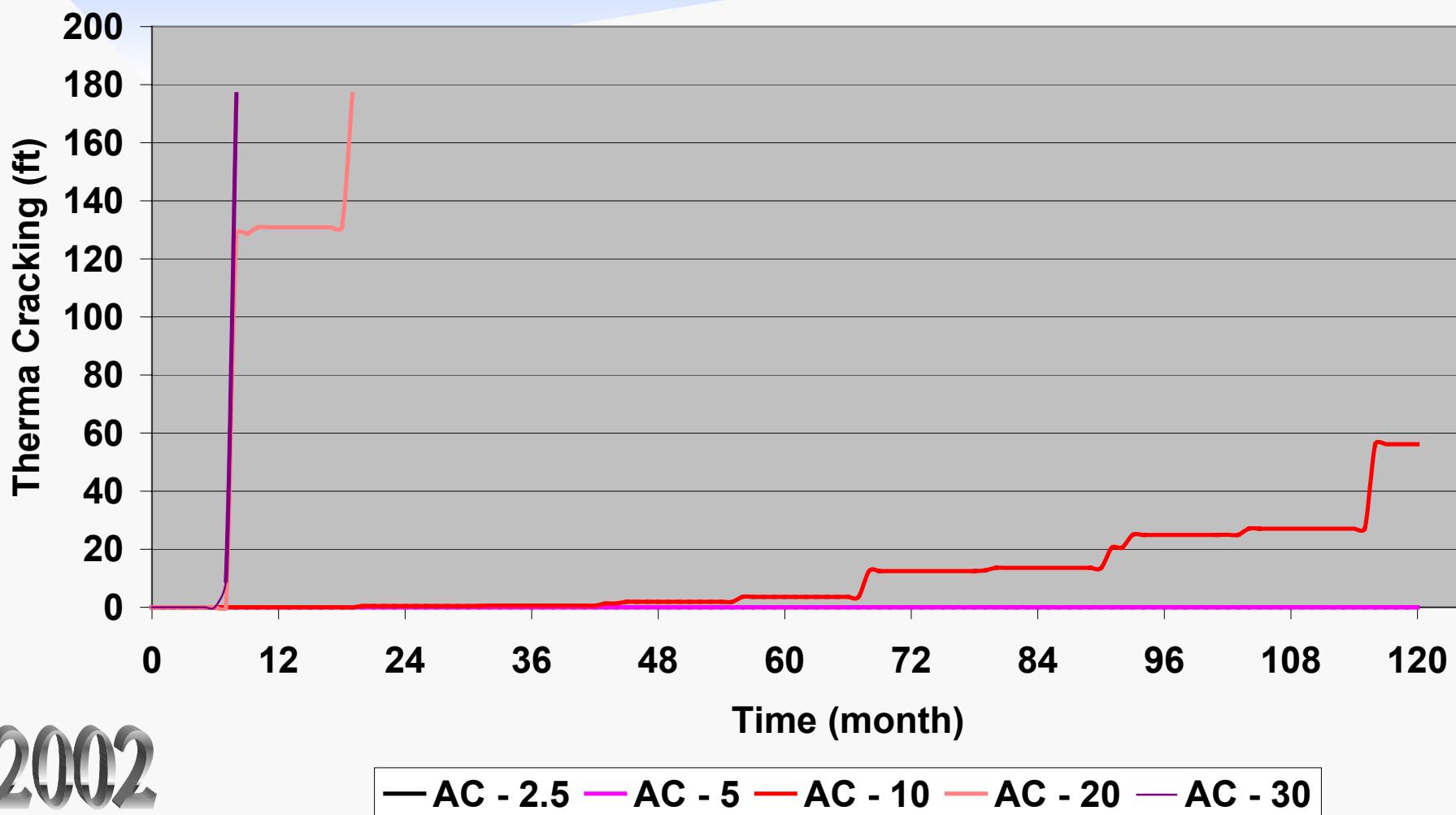
Total Rutting For Various Mixes



Example 4 – Binder Type on Thermal Cracking

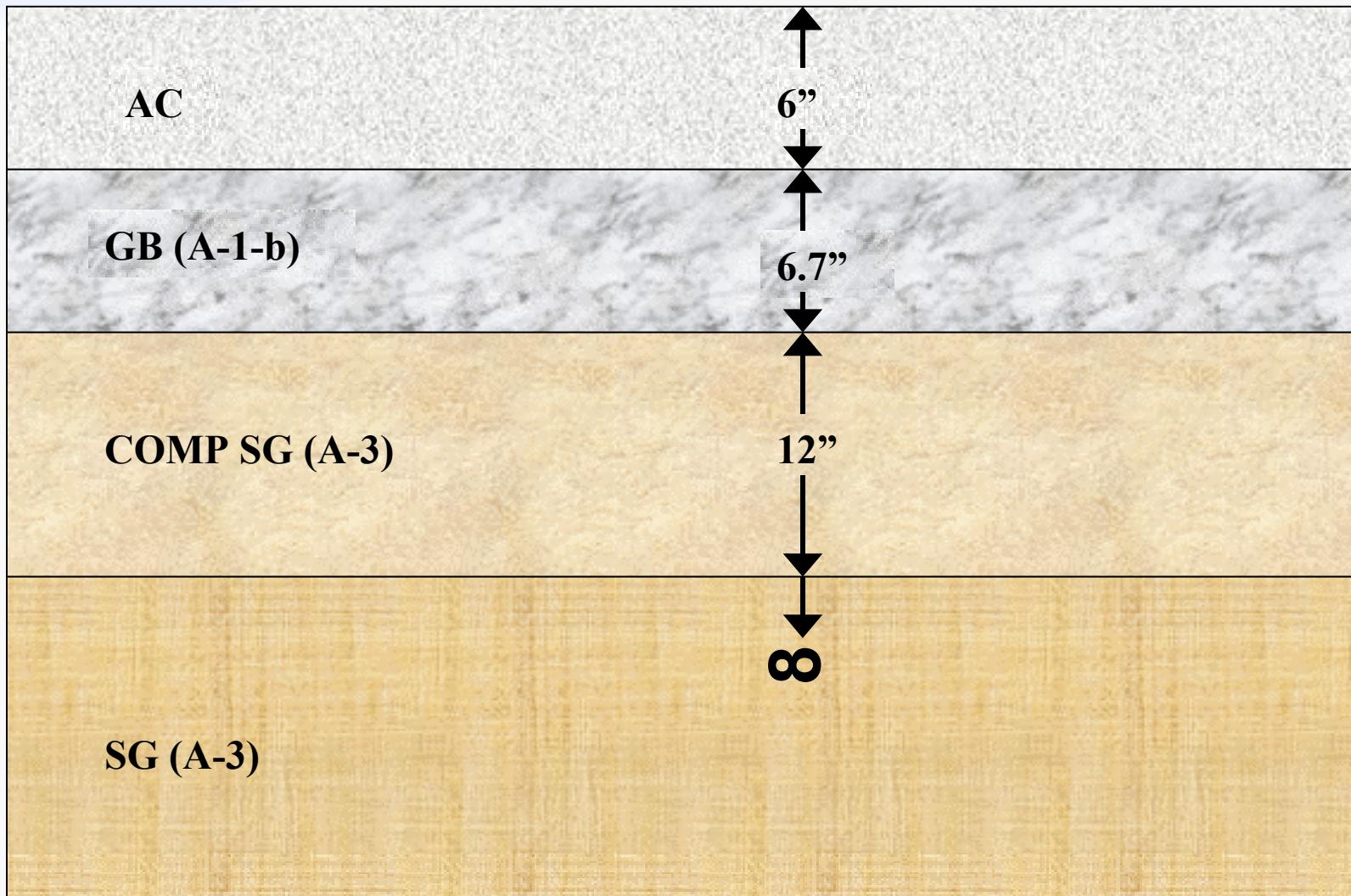


Thermal Cracking by Binder Type

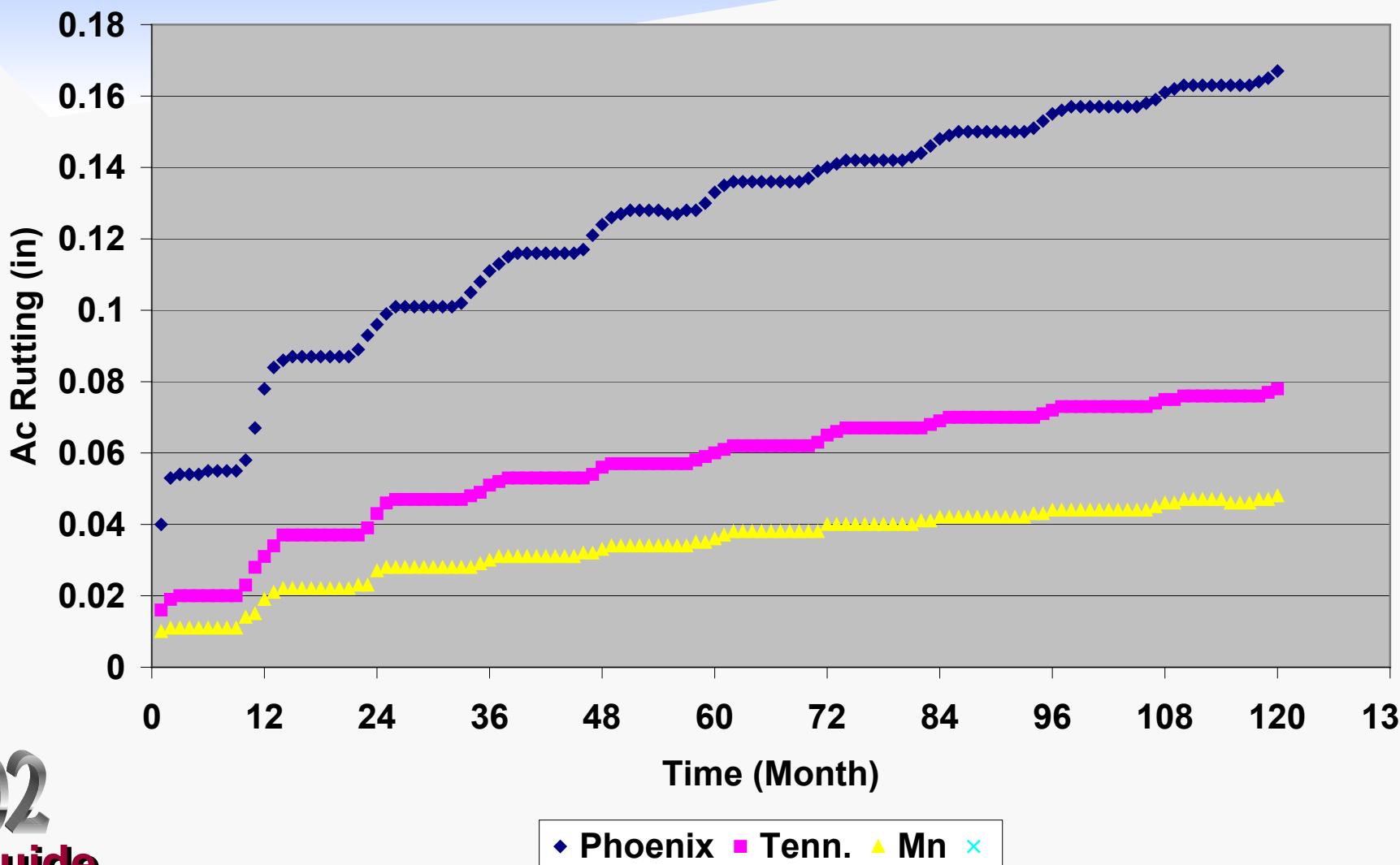


Example 5 – Mean Annual Air Temperature

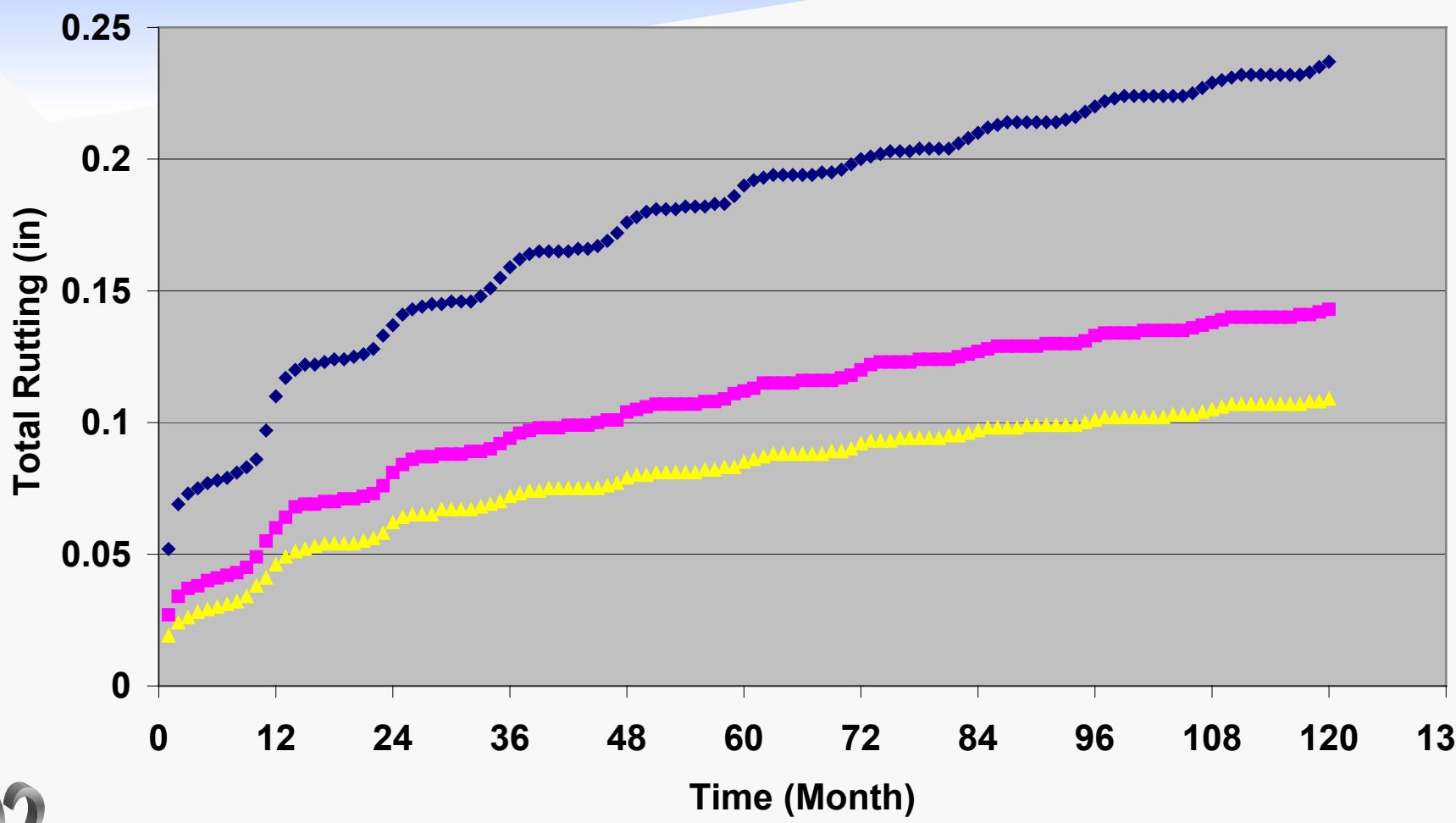
Phoenix, Tenn., MN



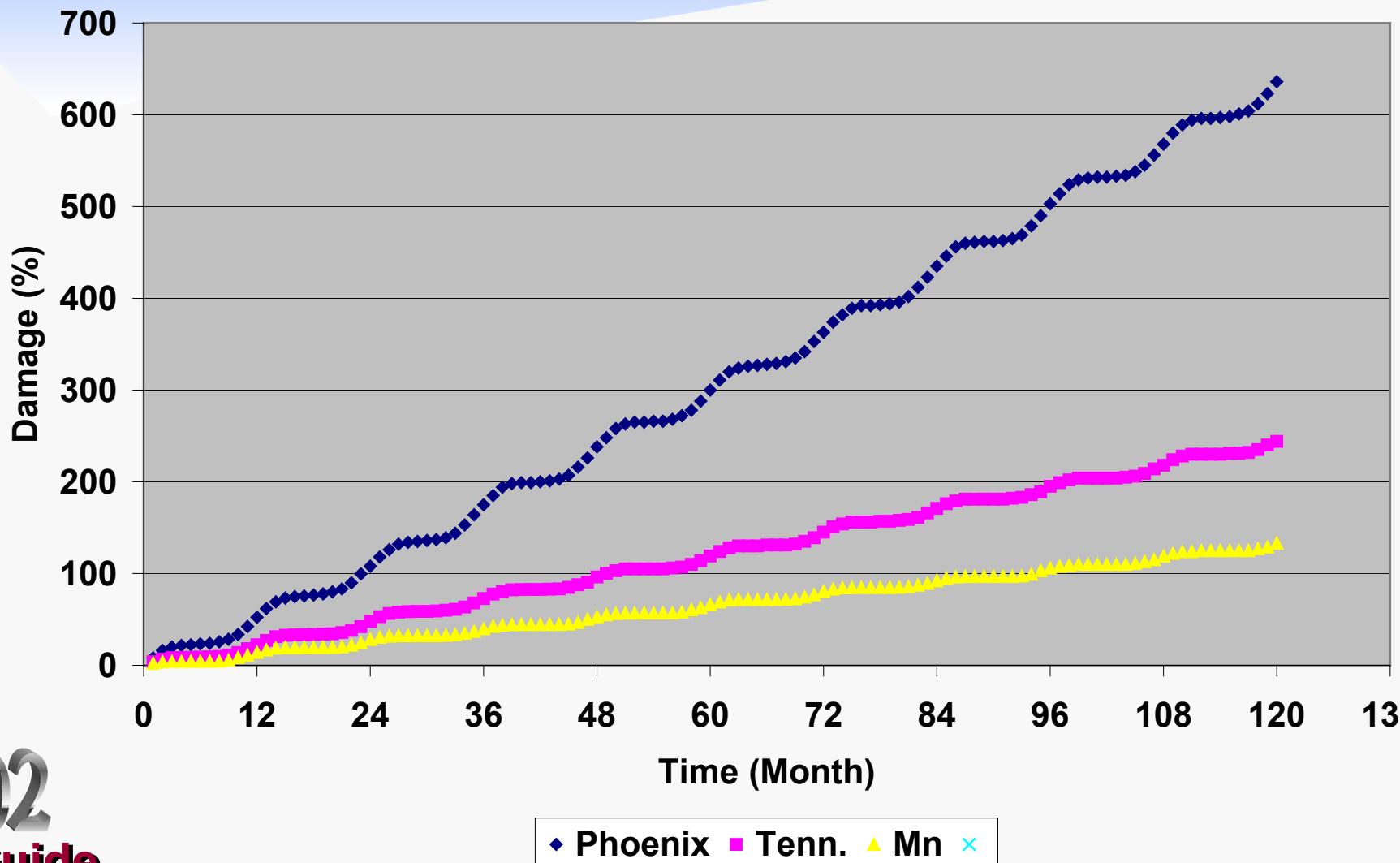
Rutting in Ac Layer



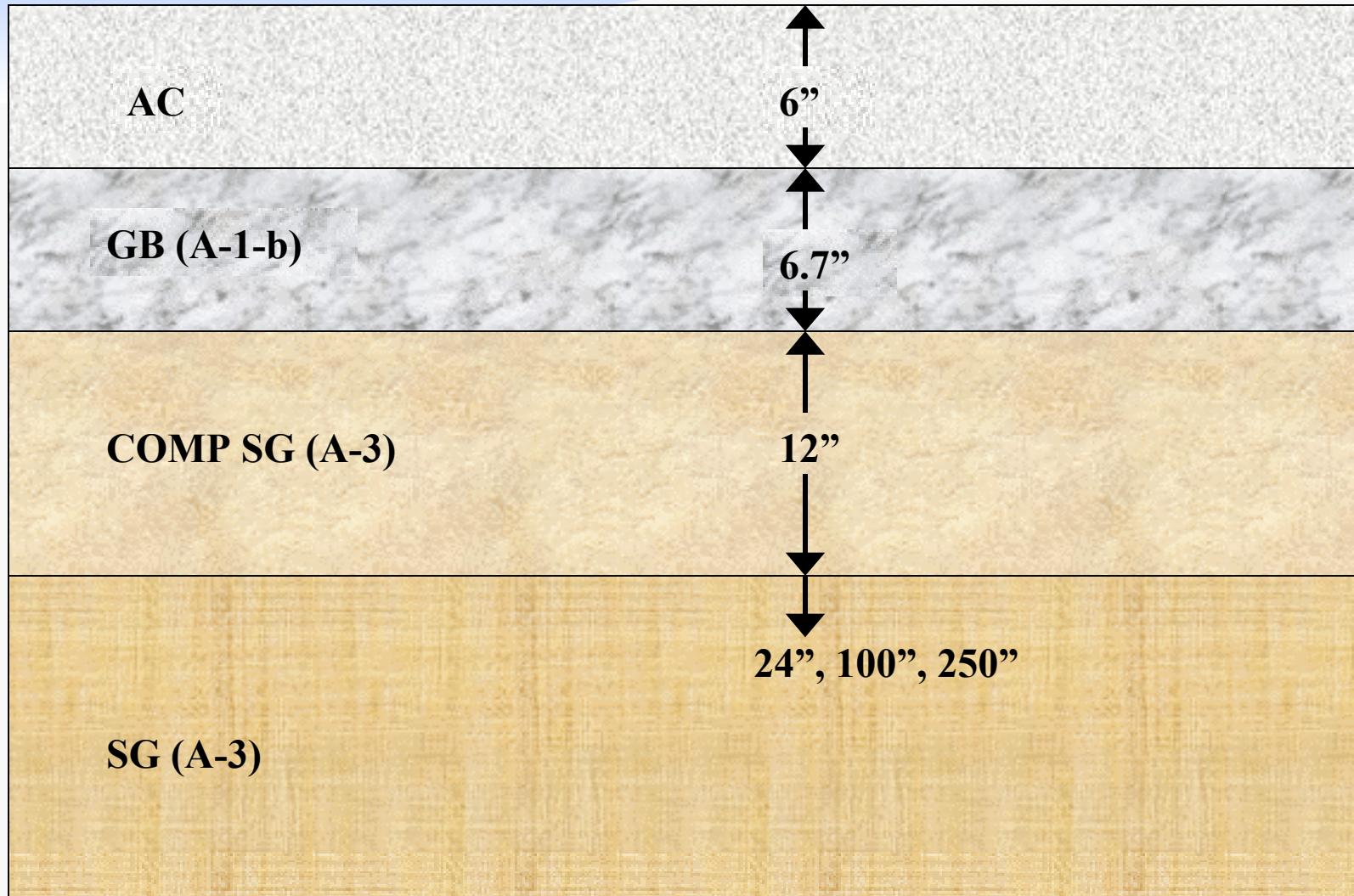
Total Rutting



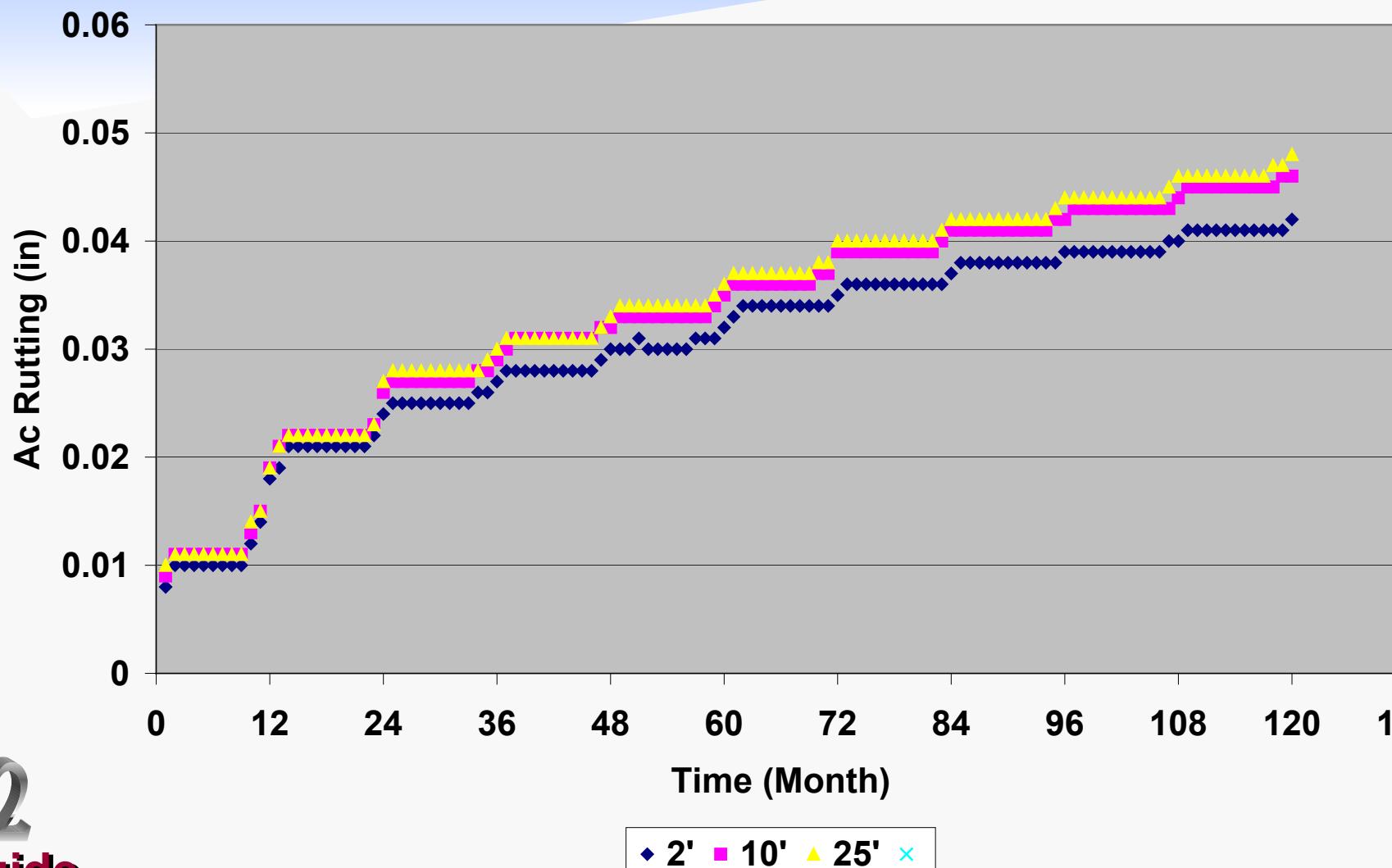
Bottom up % Damage (Alligator Cracking)



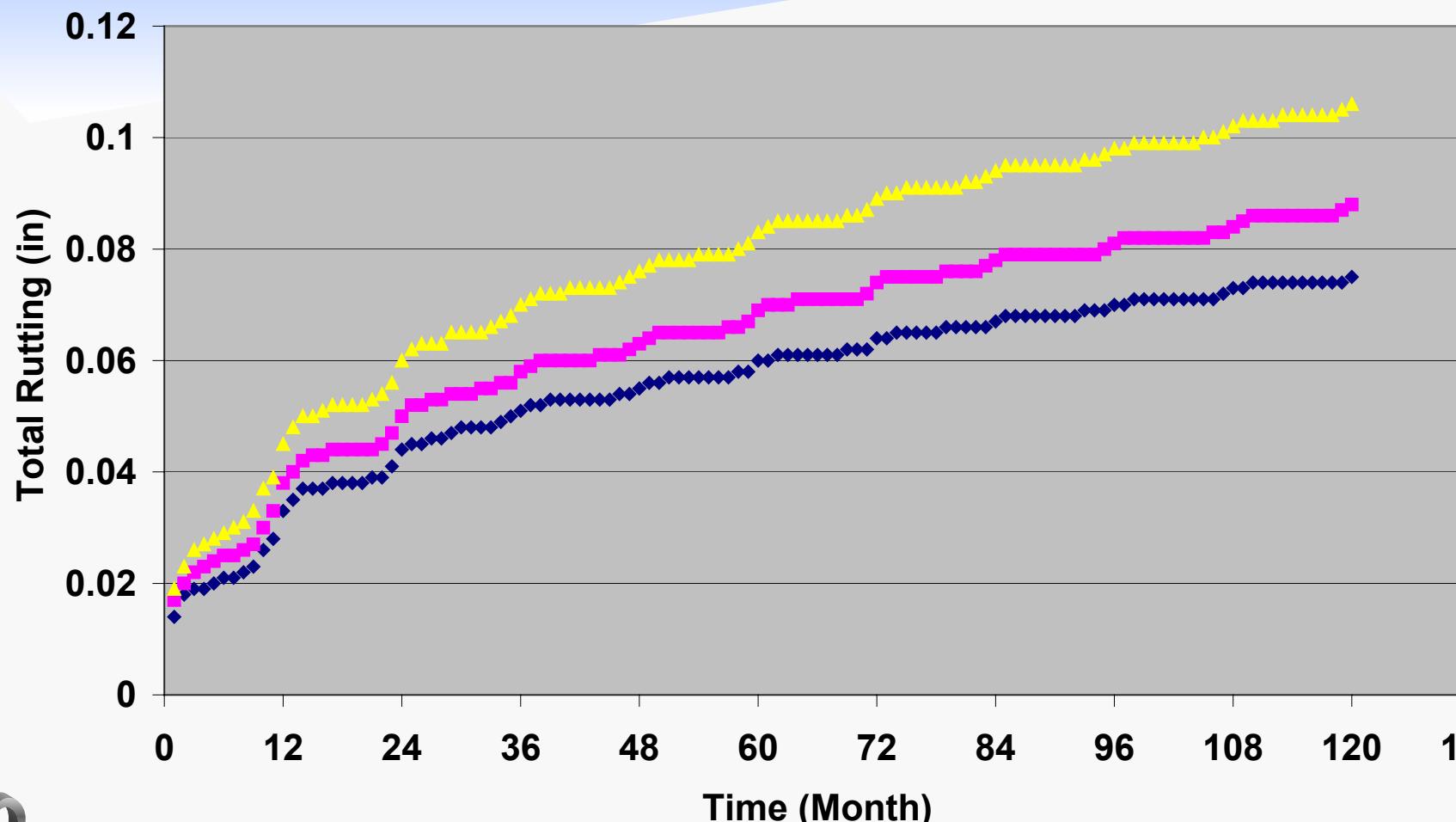
Example 6 – Bed Rock Variation



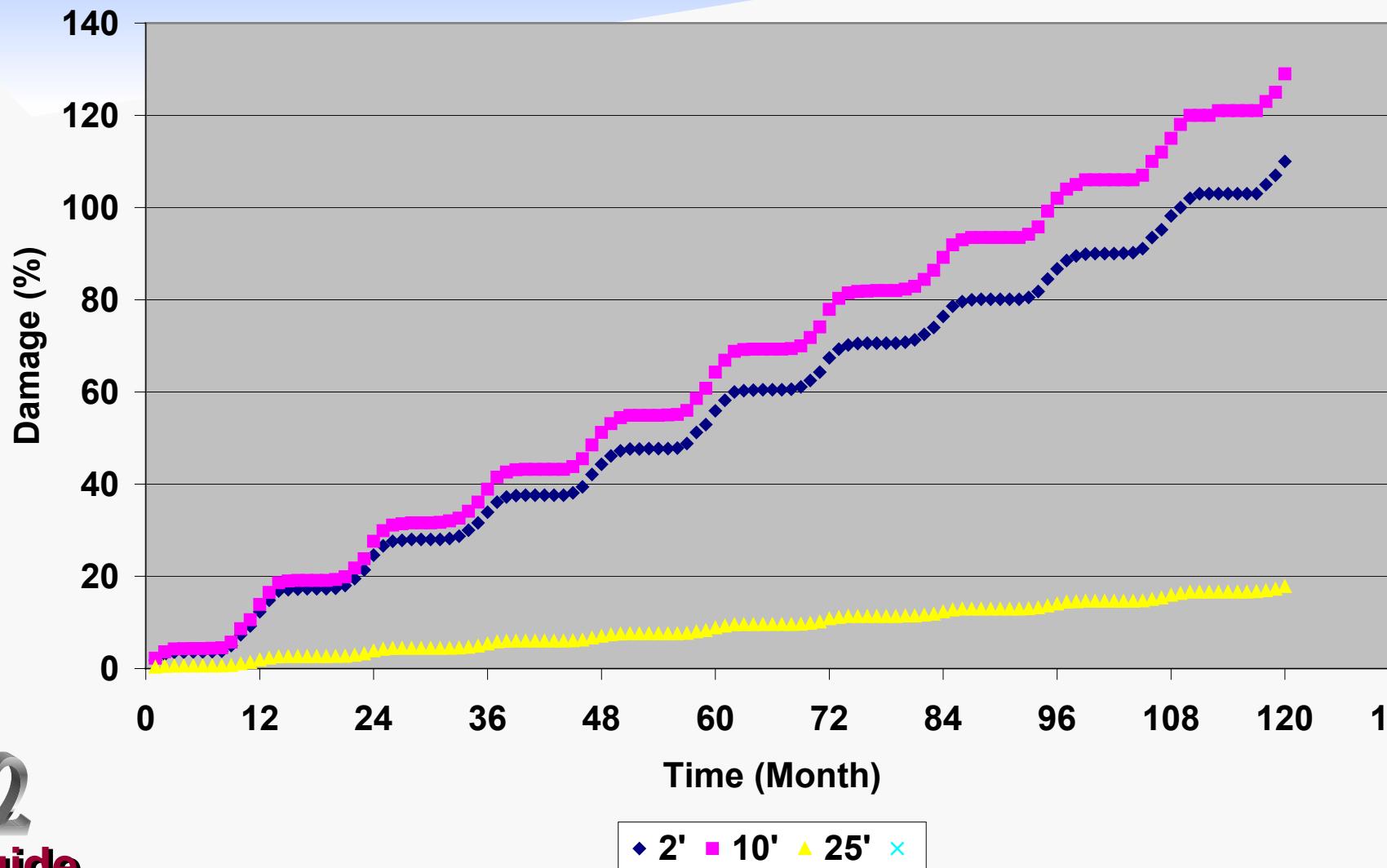
Rutting in Ac Layer



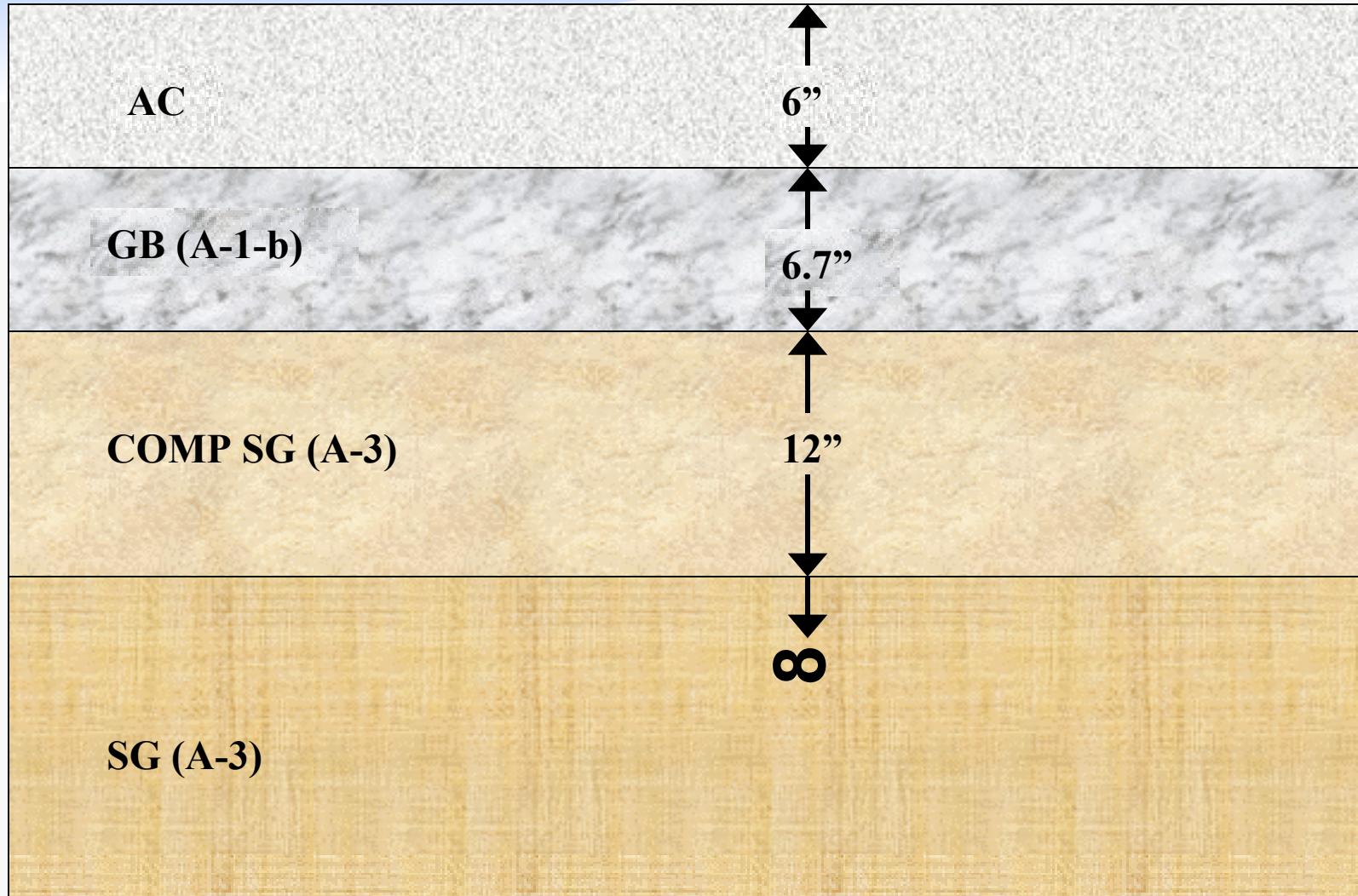
Total Rutting



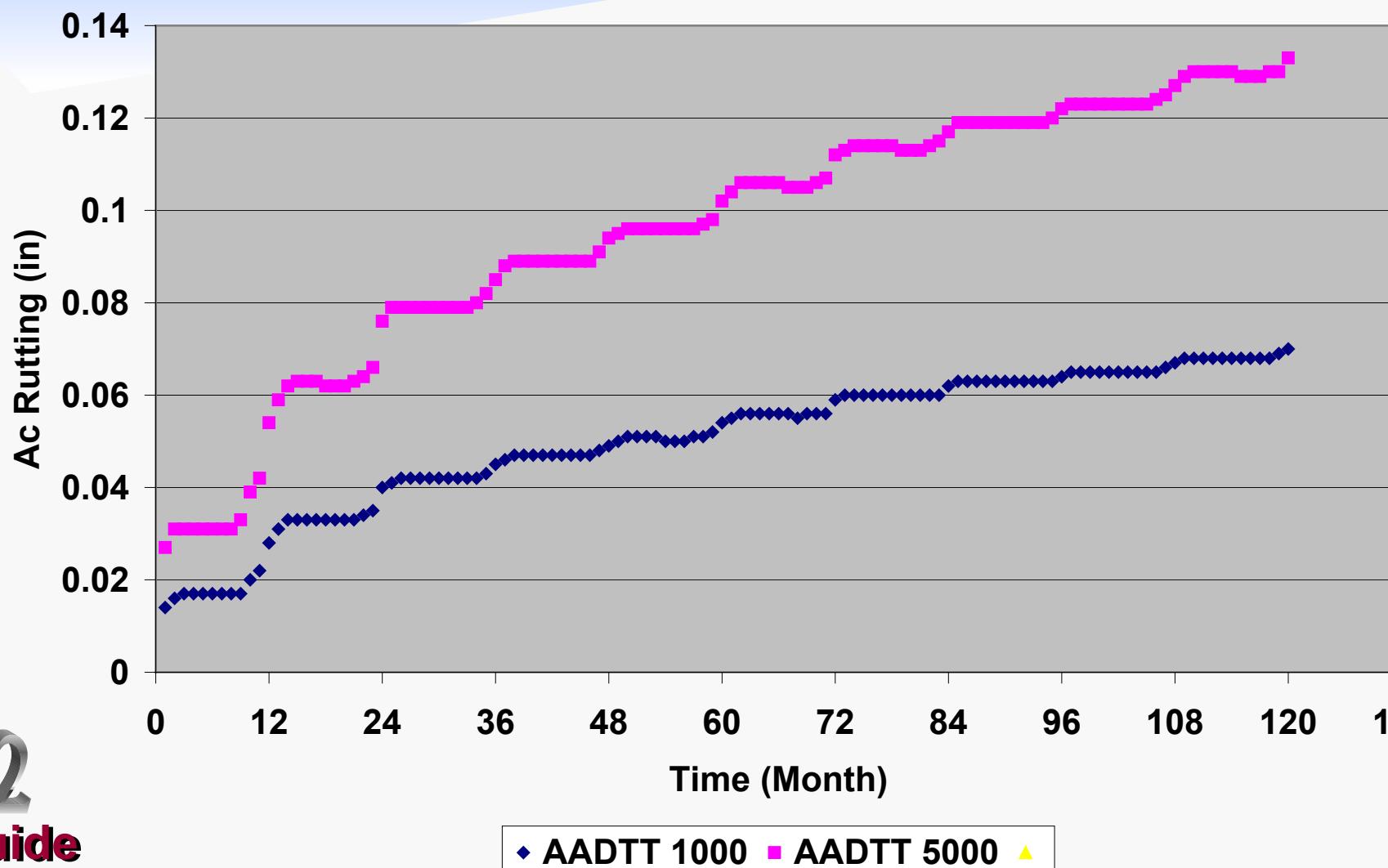
Bottom up % Damage (Alligator Cracking)

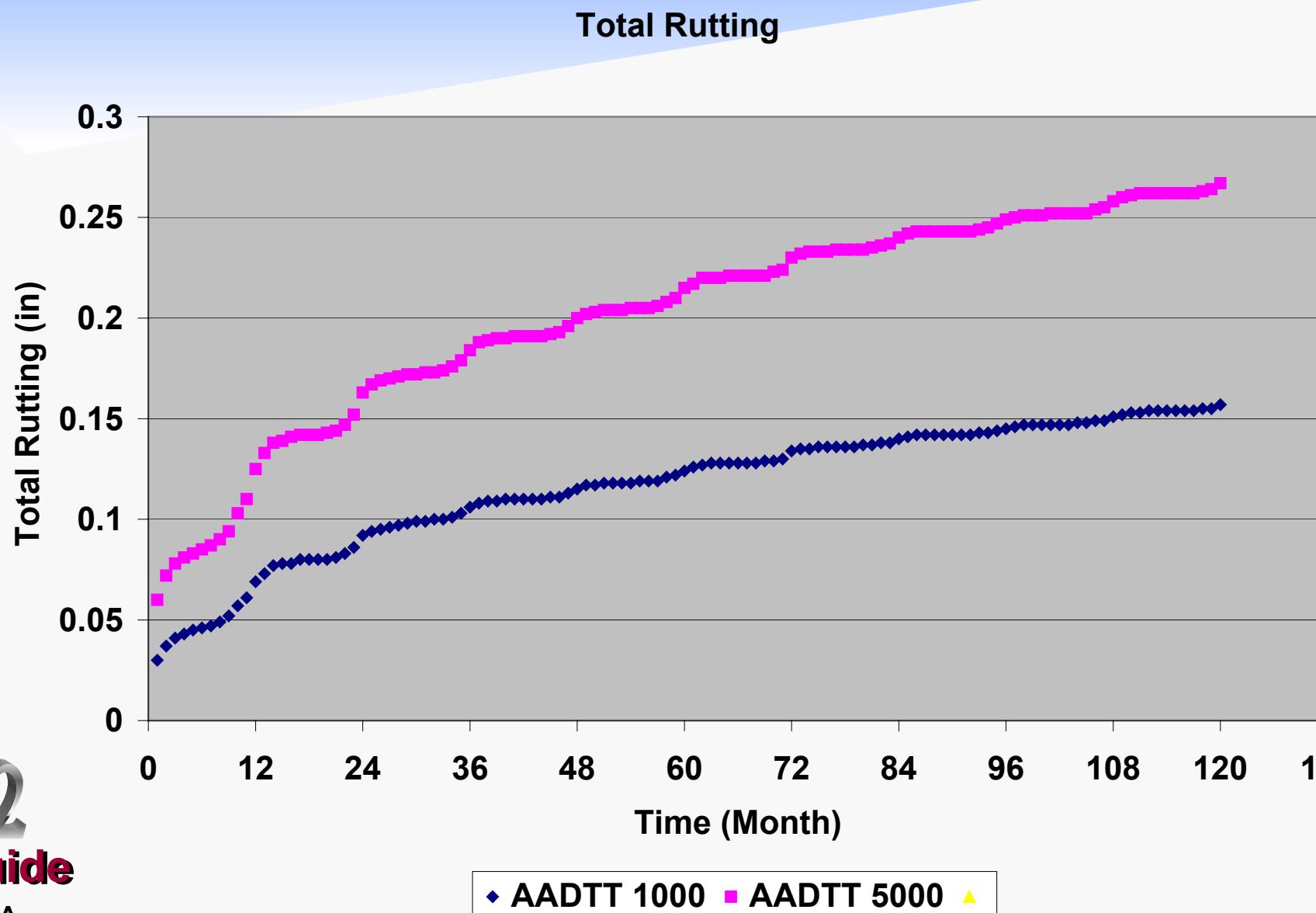


Example 7 – Traffic Variation

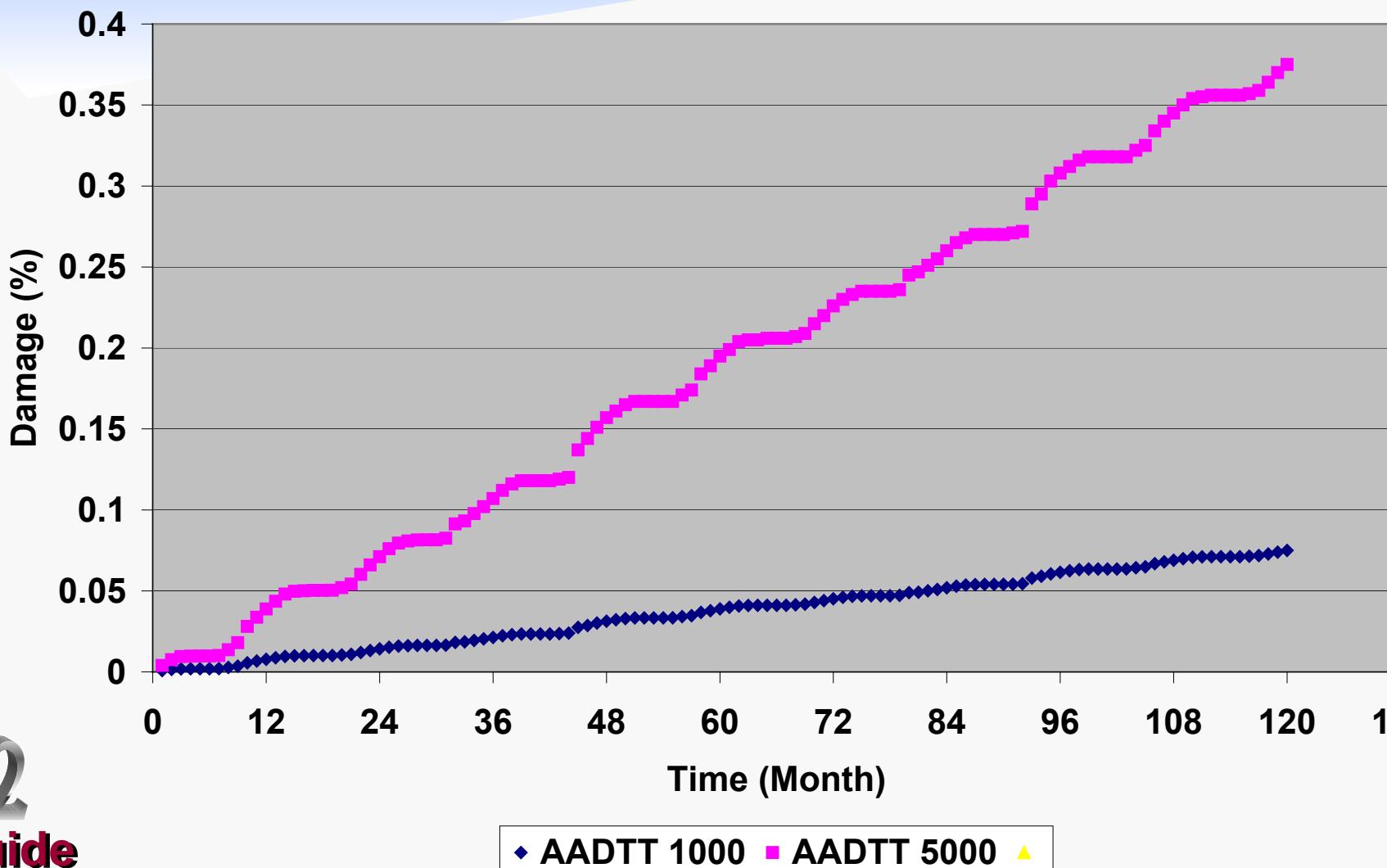


Rutting in Ac Layer

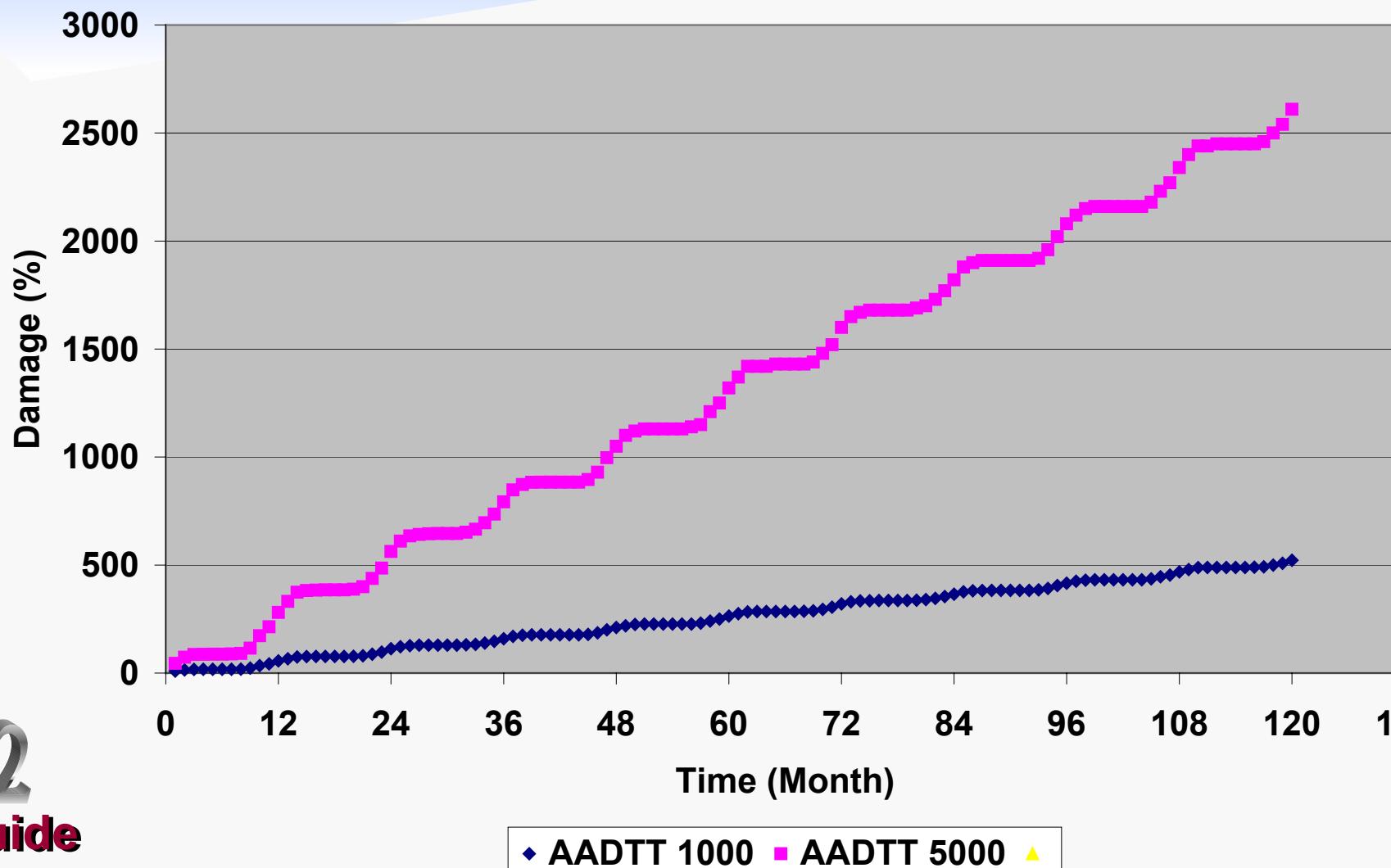




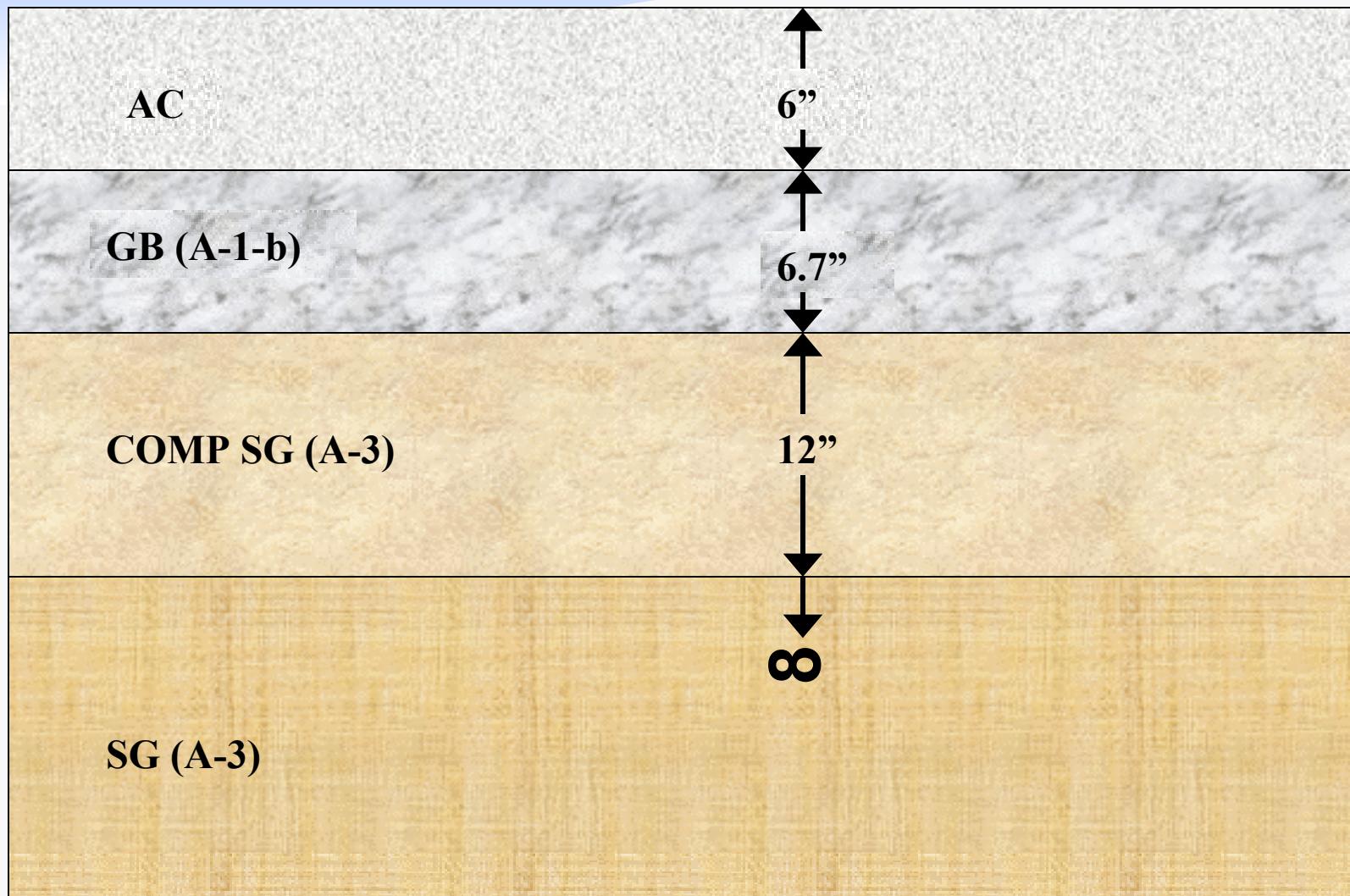
Surface Down % Damage (Longitudinal Cracking)



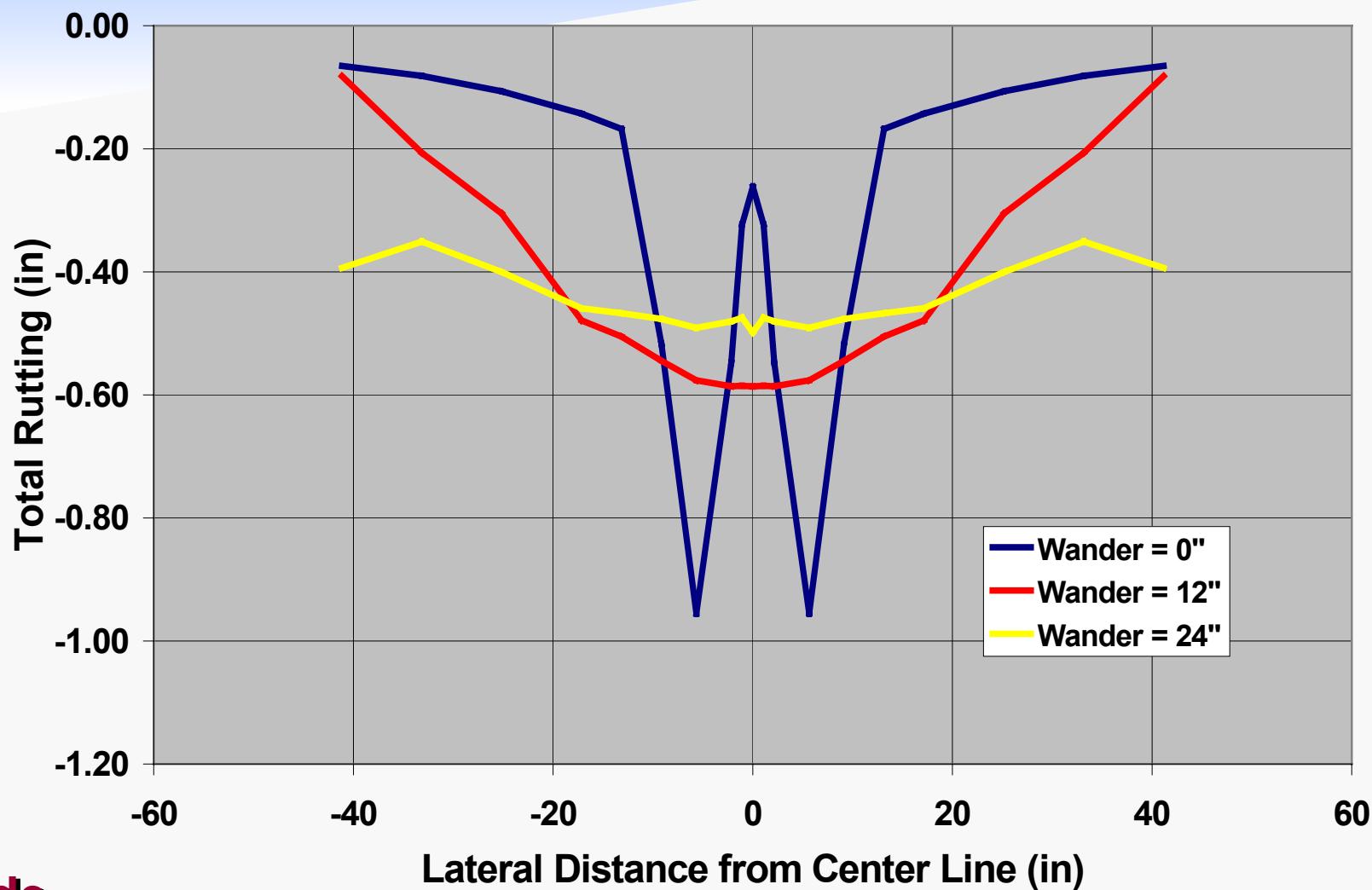
Bottom up % Damage (Alligator Cracking)



Example 8 – Traffic Wander

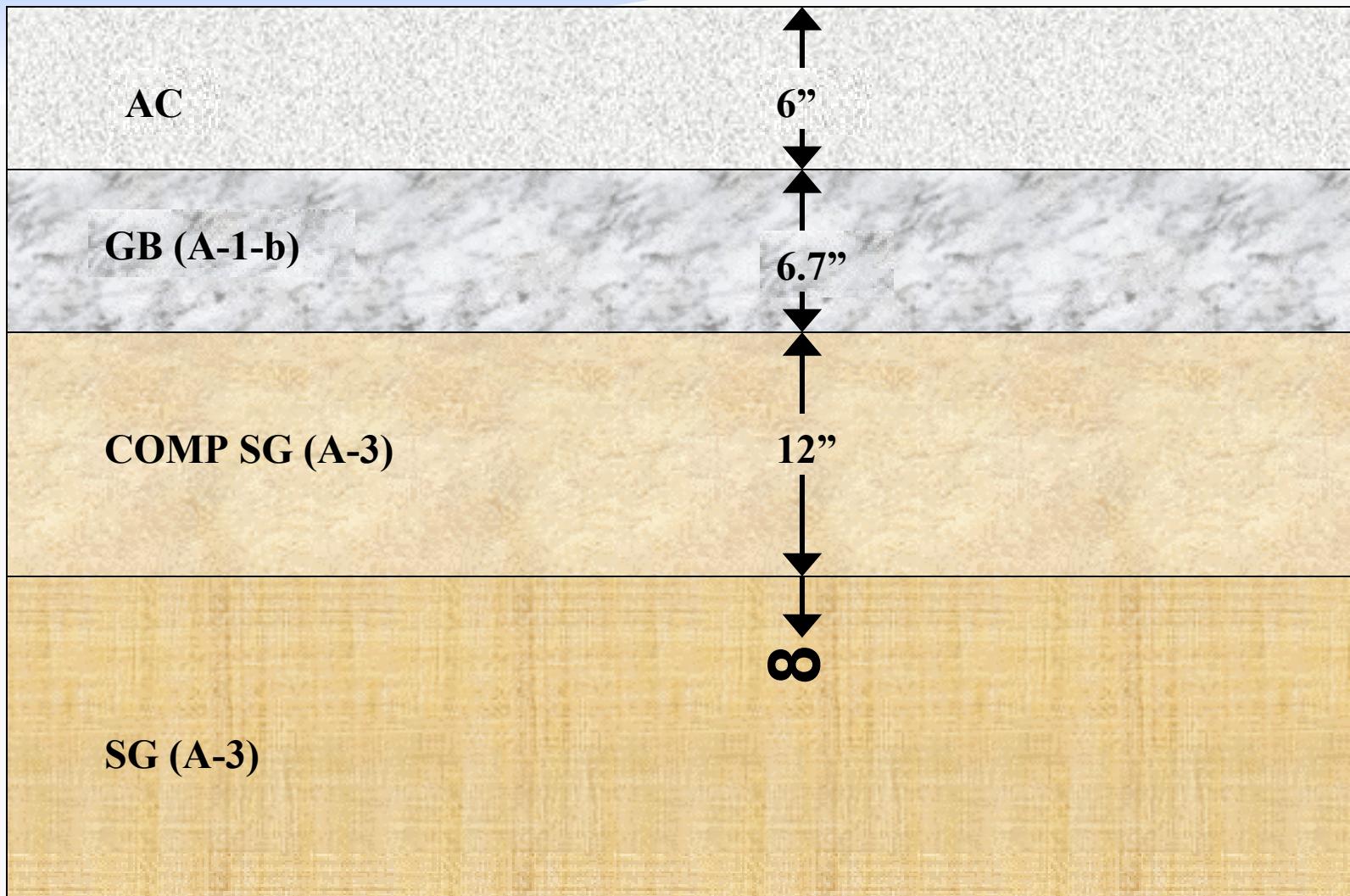


Rutting Profile with Changing Wander

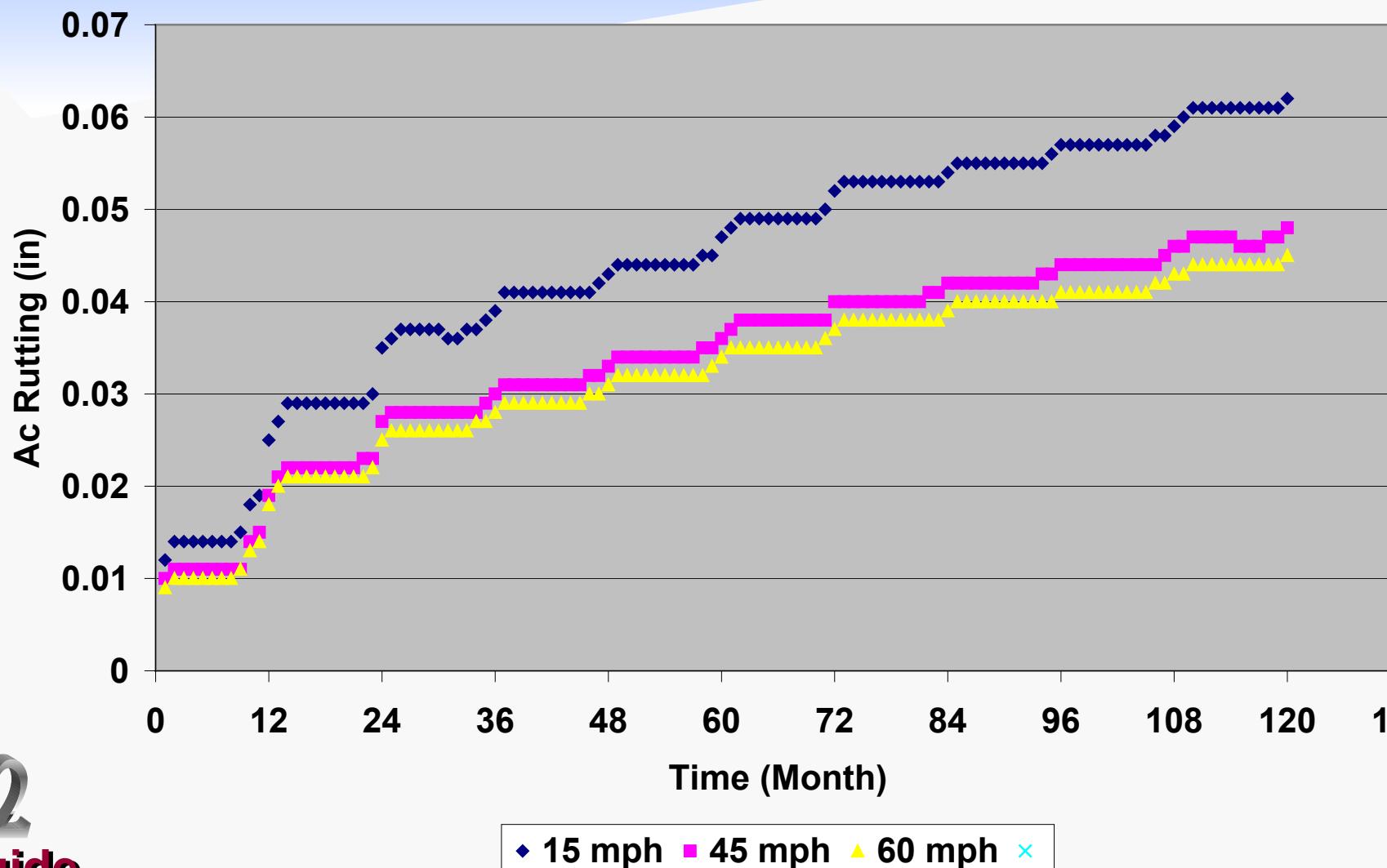


Example 9 – Traffic Speed

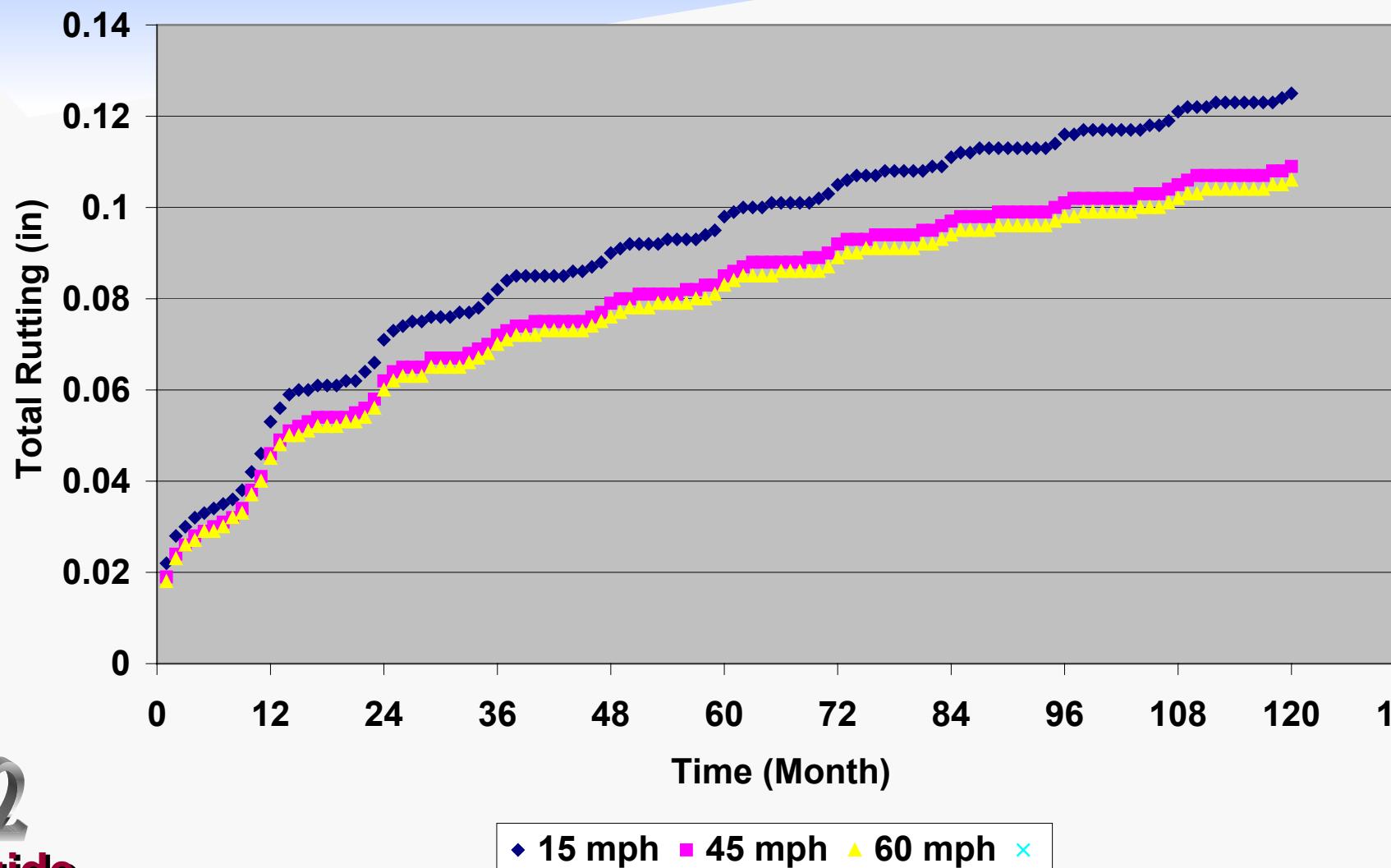
15, 45, 60 mph



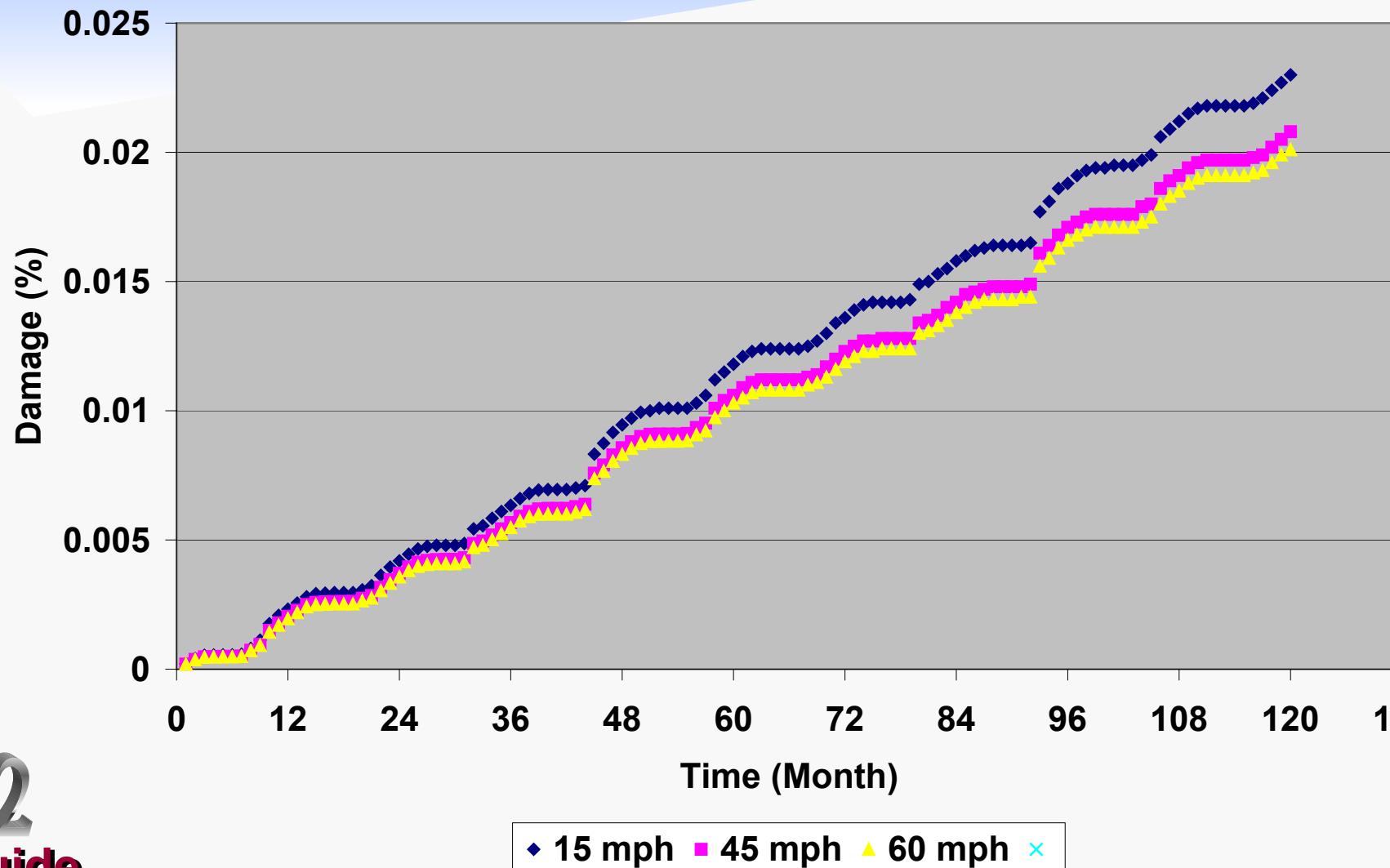
Rutting in Ac Layer



Total Rutting



Surface Down % Damage (Longitudinal Cracking)



Bottom up % Damage (Alligator Cracking)

